Herschel observations of the dust factories in galaxies: dusty stars and supernovae

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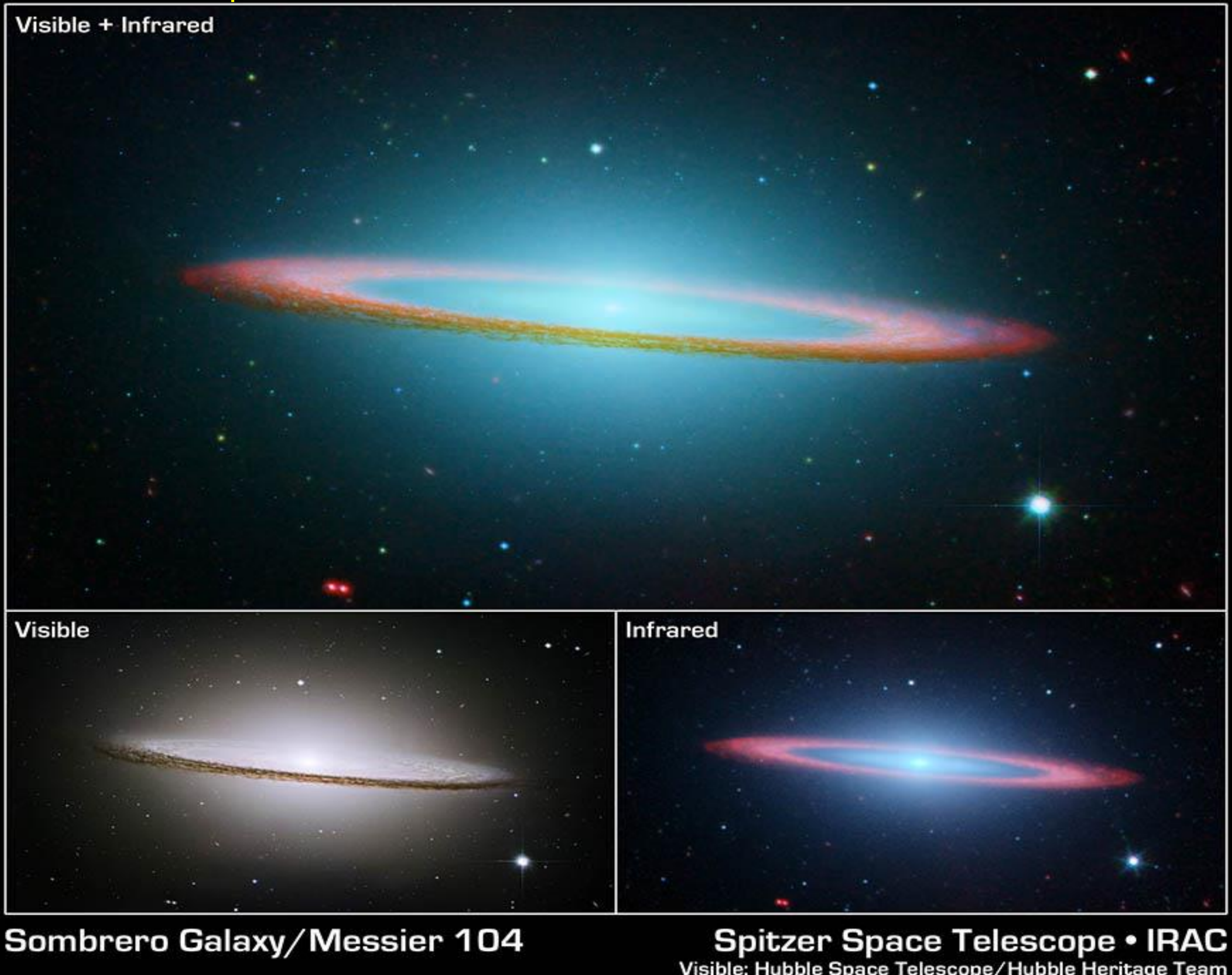
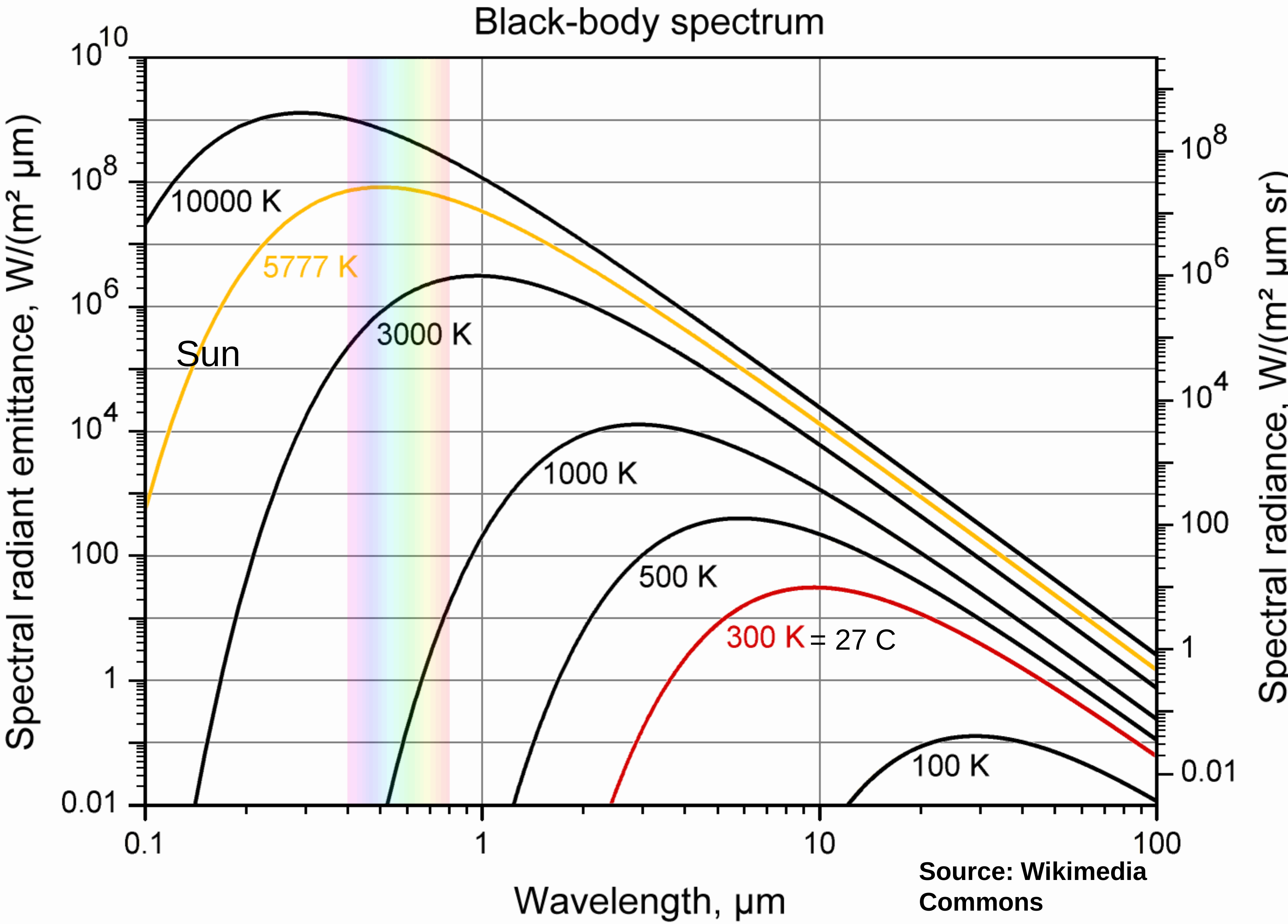
Results from the Herschel Space Observatory

EEESTA Seminar November 14th 2012

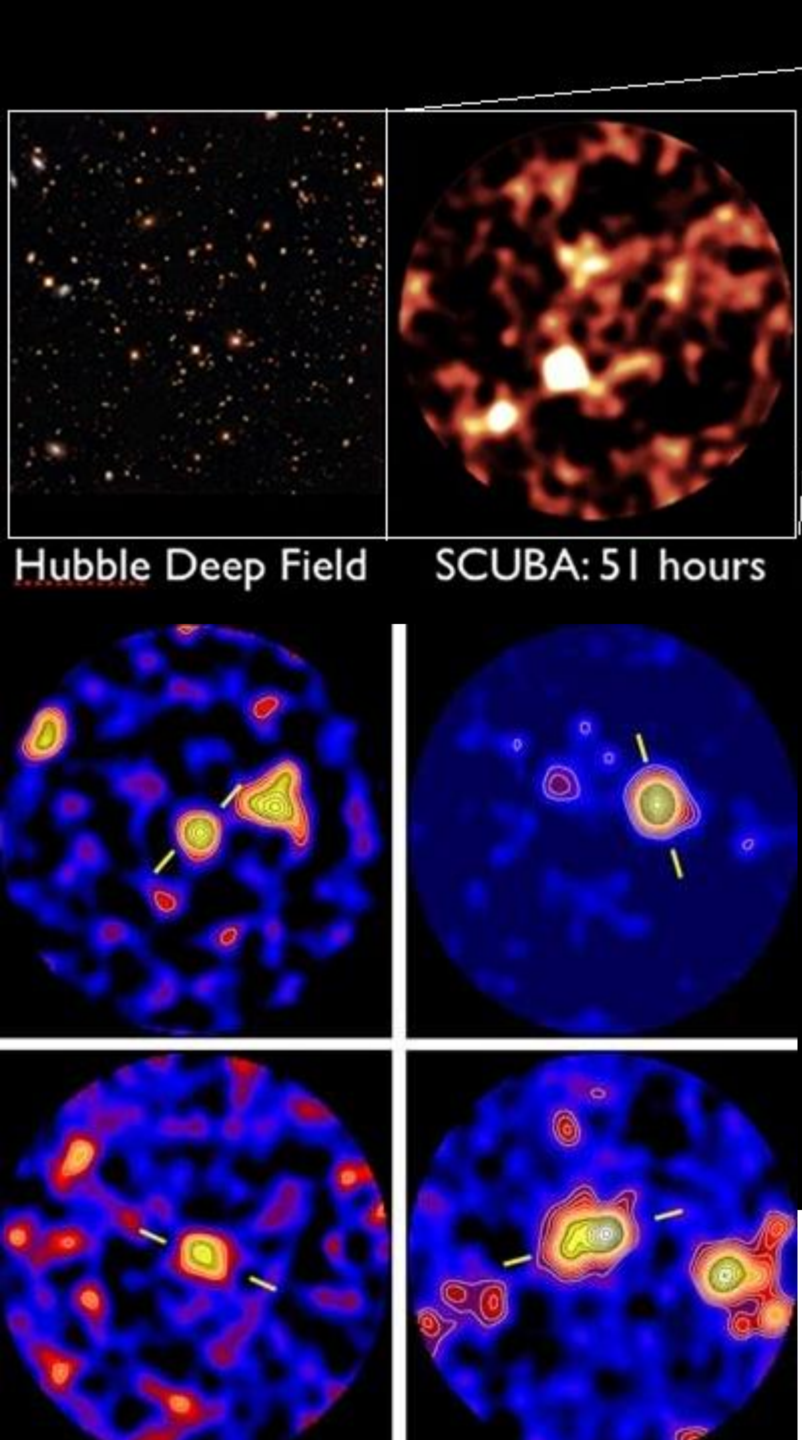

Barnard 68 dark cloud
We see evidence of obscuring interstellar dust at visible wavelengths (0.4-0.7 microns)
ESO VLT

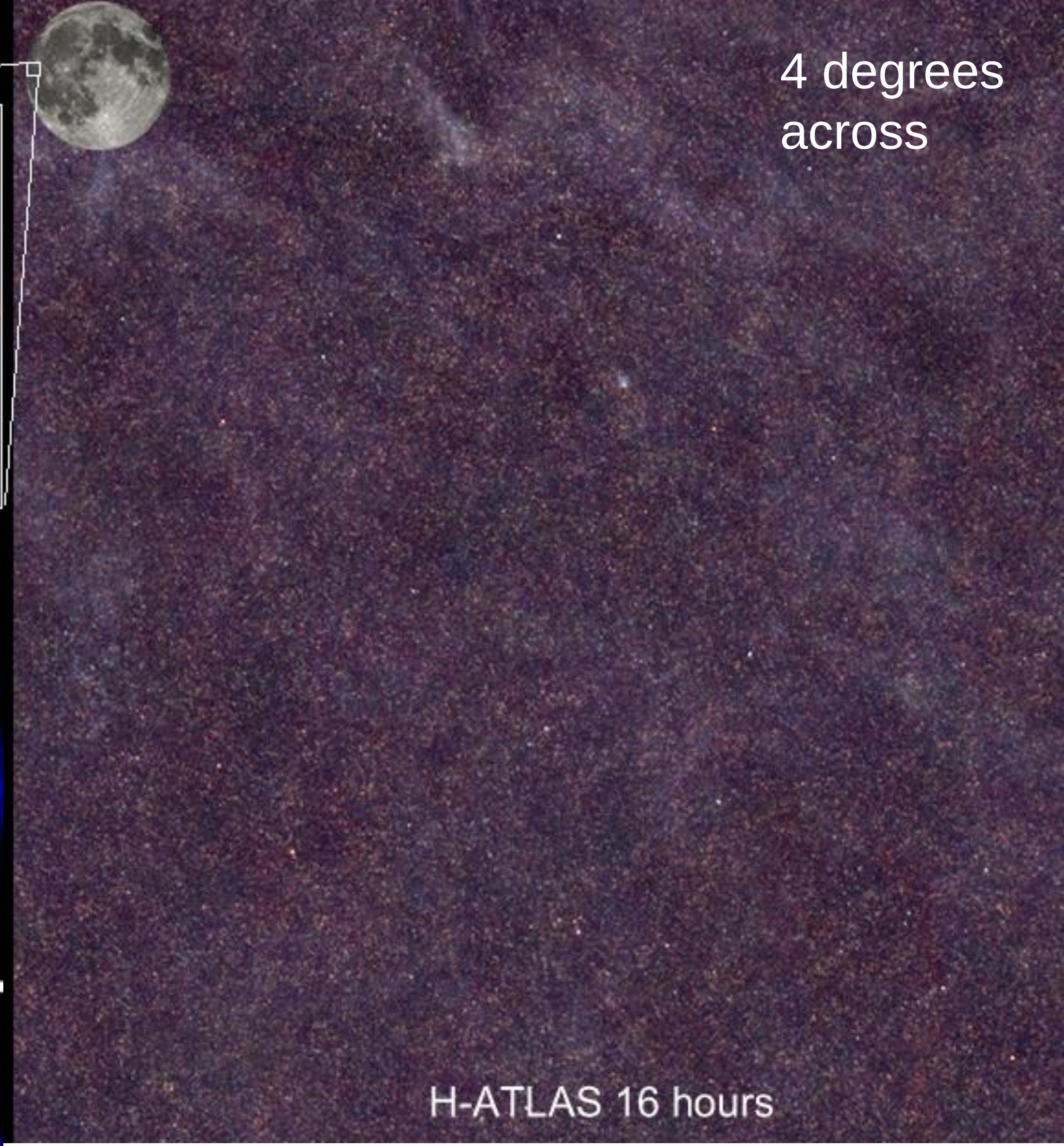
Dust particles that absorb in the visible re-emit in the infrared





Source: Wikimedia Commons



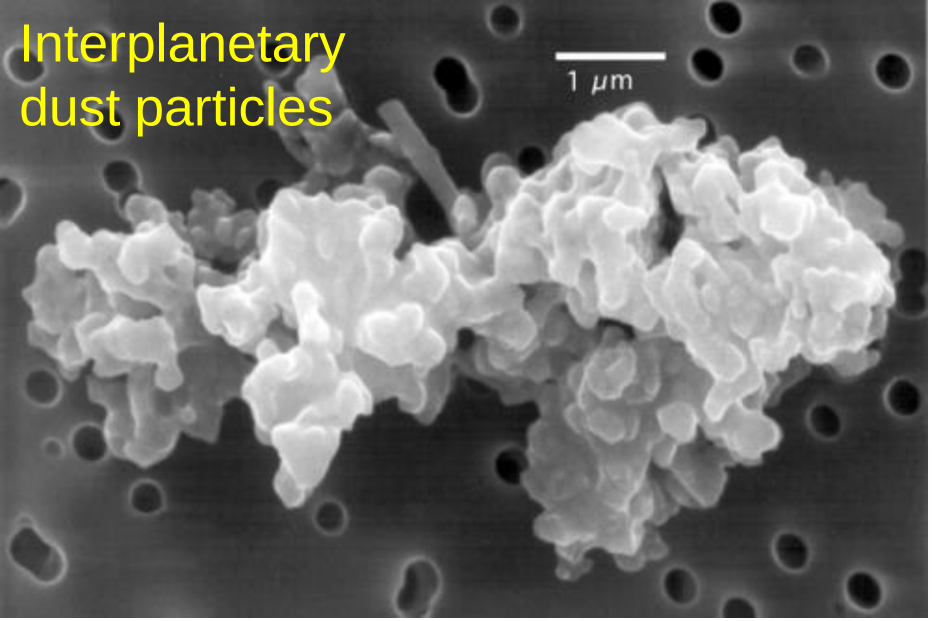


Herschel-SPIRE high redshift galaxies

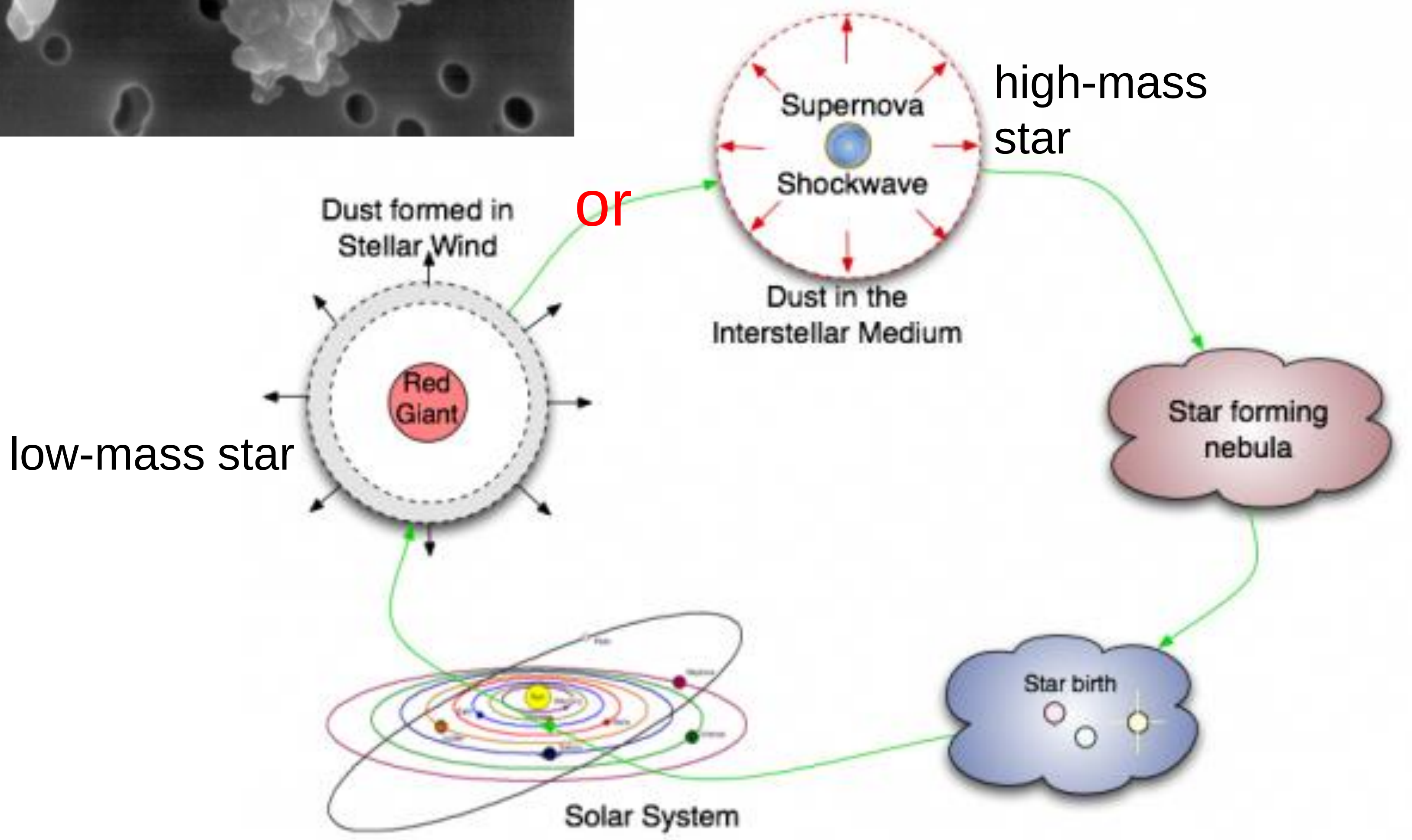
←SCUBA IR-emitting high redshift galaxies

Herschel-SPIRE images of two deep extragalactic fields, showing tens of thousand of distant dusty infrared-emitting galaxies.

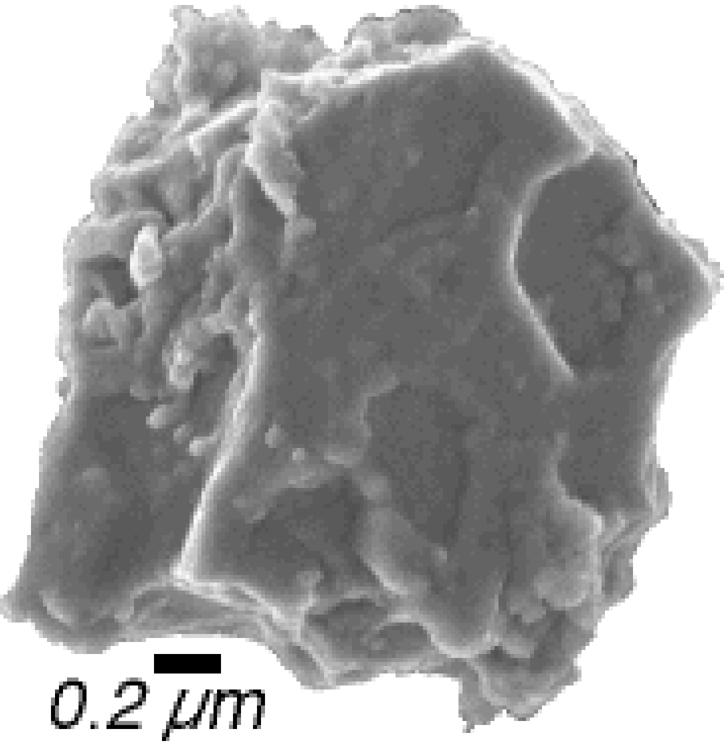
Where did the dust in these galaxies come from?

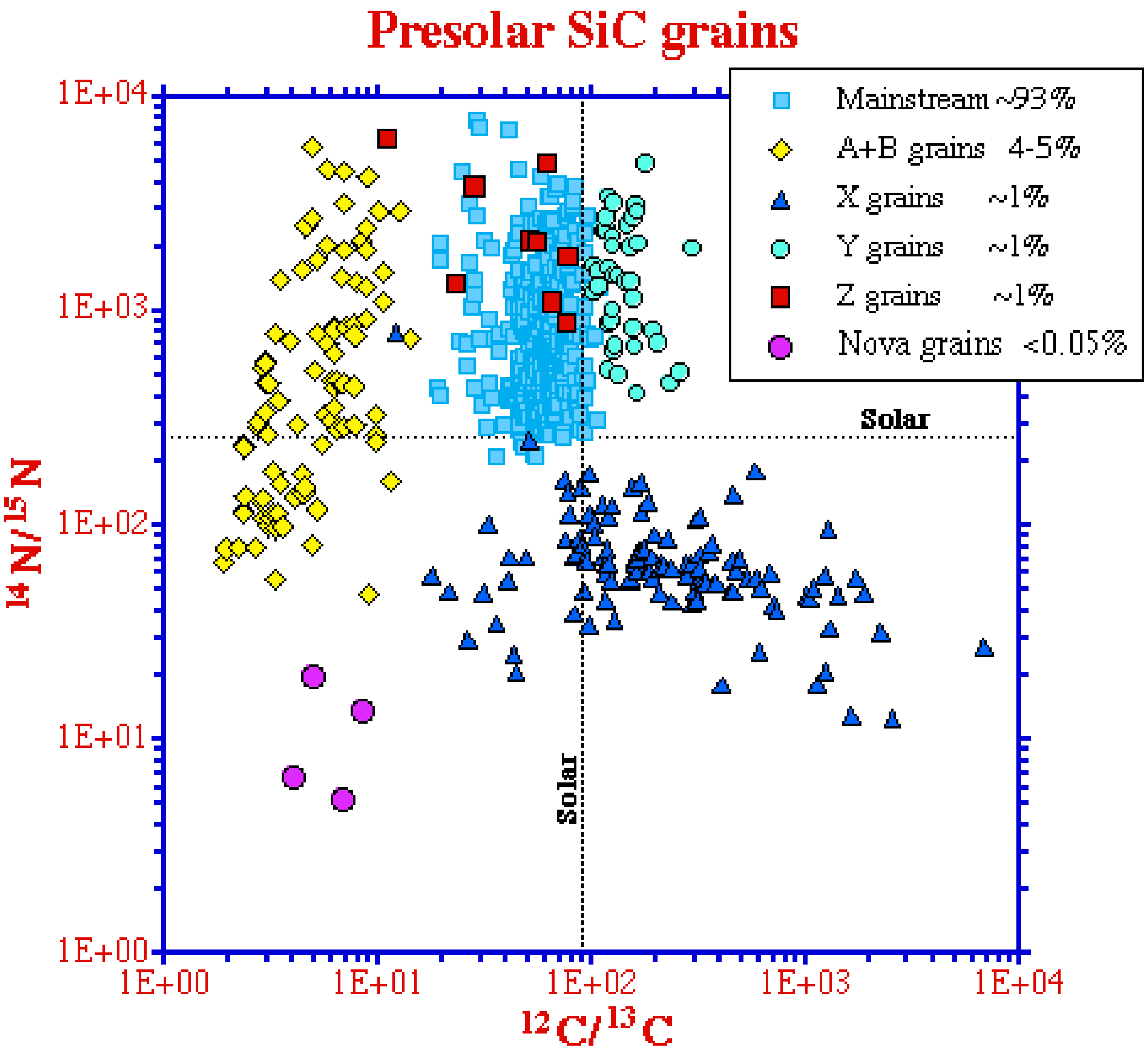


The life-cycle of cosmic dust

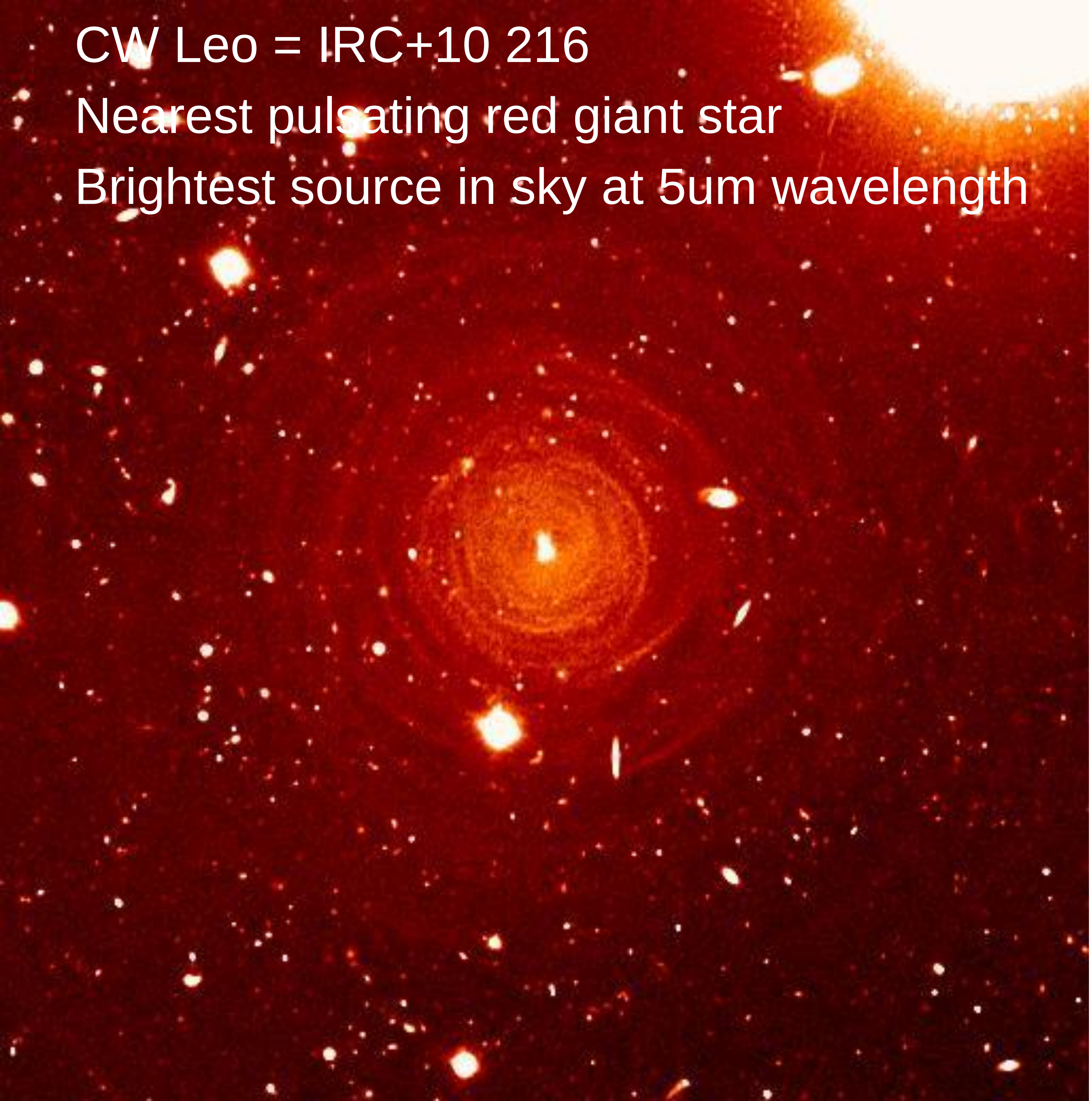


Pre-solar meteoritic grain *inclusions* include examples with isotopes that indicate a red giant origin, while others indicate a supernova origin





from http://presolar.wustl.edu/work/grains.html#SurfaceProperties



CW Leo:

ESO VLT visible image (0.5 microns)

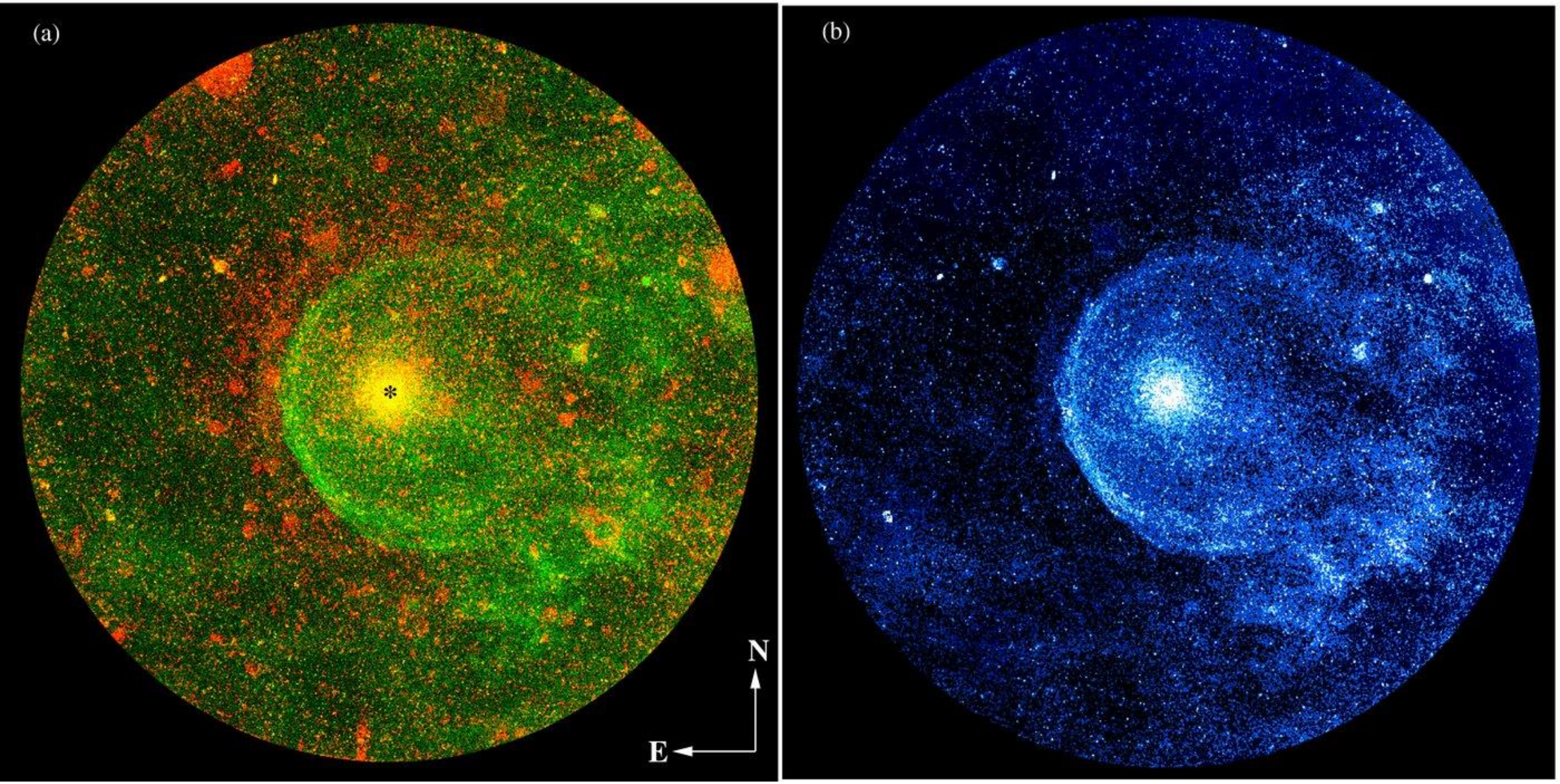
200x200 arcsecs

Distance ~150 pc = 490 light-years

Star is 10,000 times more luminous than the Sun

The star can't be seen directly in the visible, due to obscuration by the dust formed in its outflow; what we see is light reflected by the dust

GALEX ultraviolet images of the bow-shock around CW Leo



Left: Near-UV + Far-UV

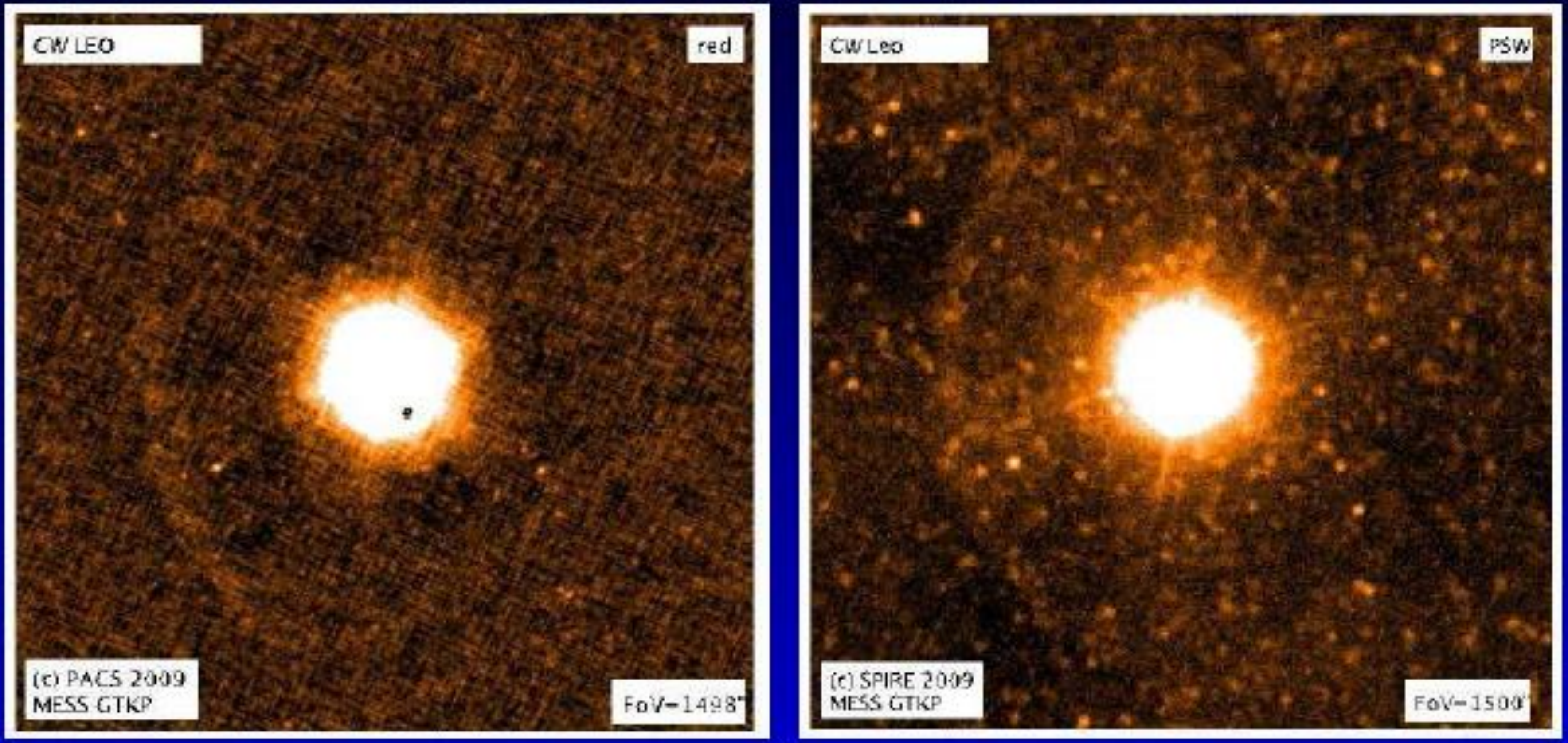
Right: Far-UV only

The UV emission is diffuse interstellar starlight reflected by dust in the bow-shock

CW Leo

25x25 arcmin Herschel images

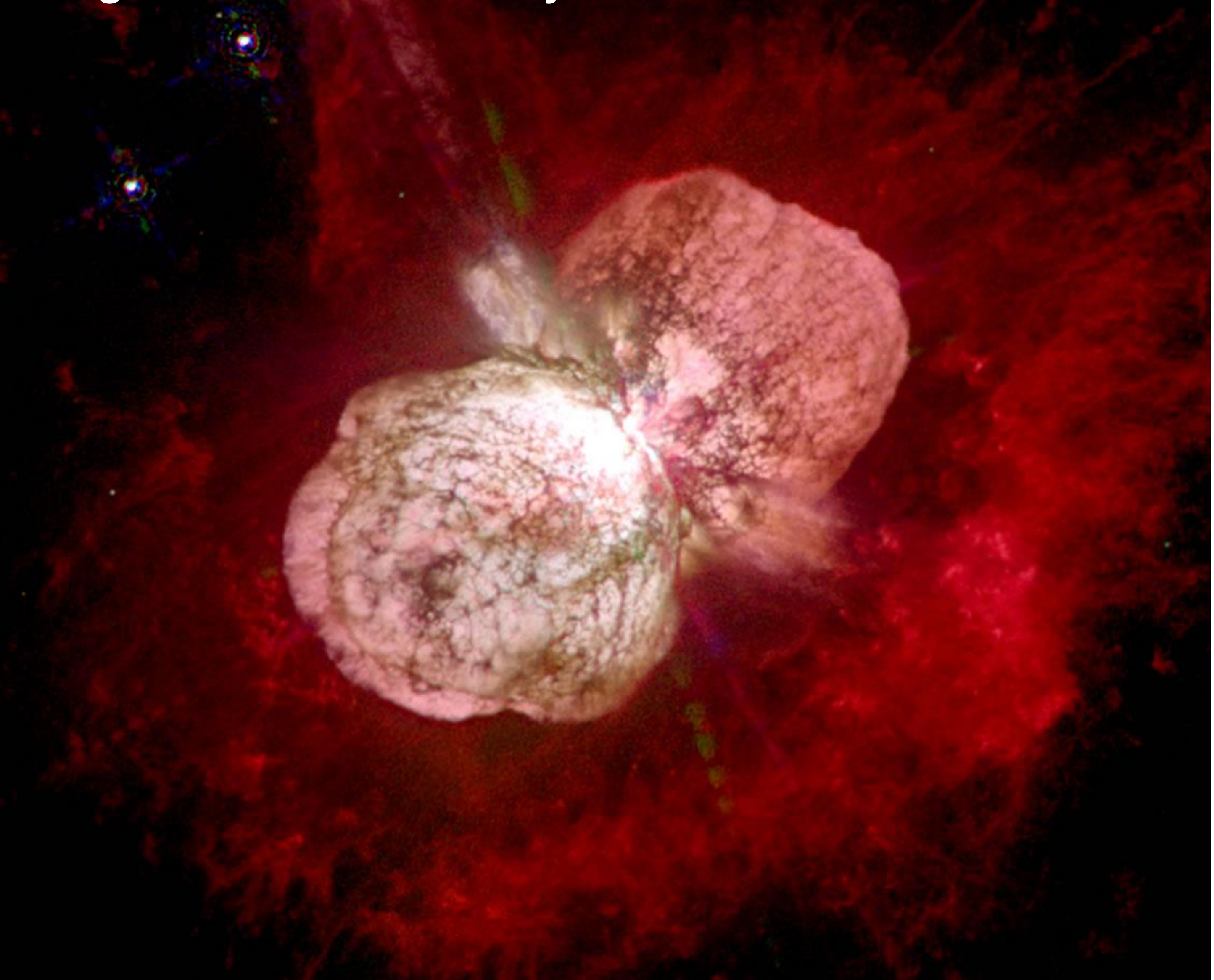
Far-infrared emission from dust in the bow-shock



PACS 160 and SPIRE 250 micron

$8.2' \times 9.2' \Rightarrow$ flow-timescale $\sim$11 000 years

Eta Carinae:
Brightest source in sky at 10 and 20 microns



Hubble visible image (~0.5 microns)

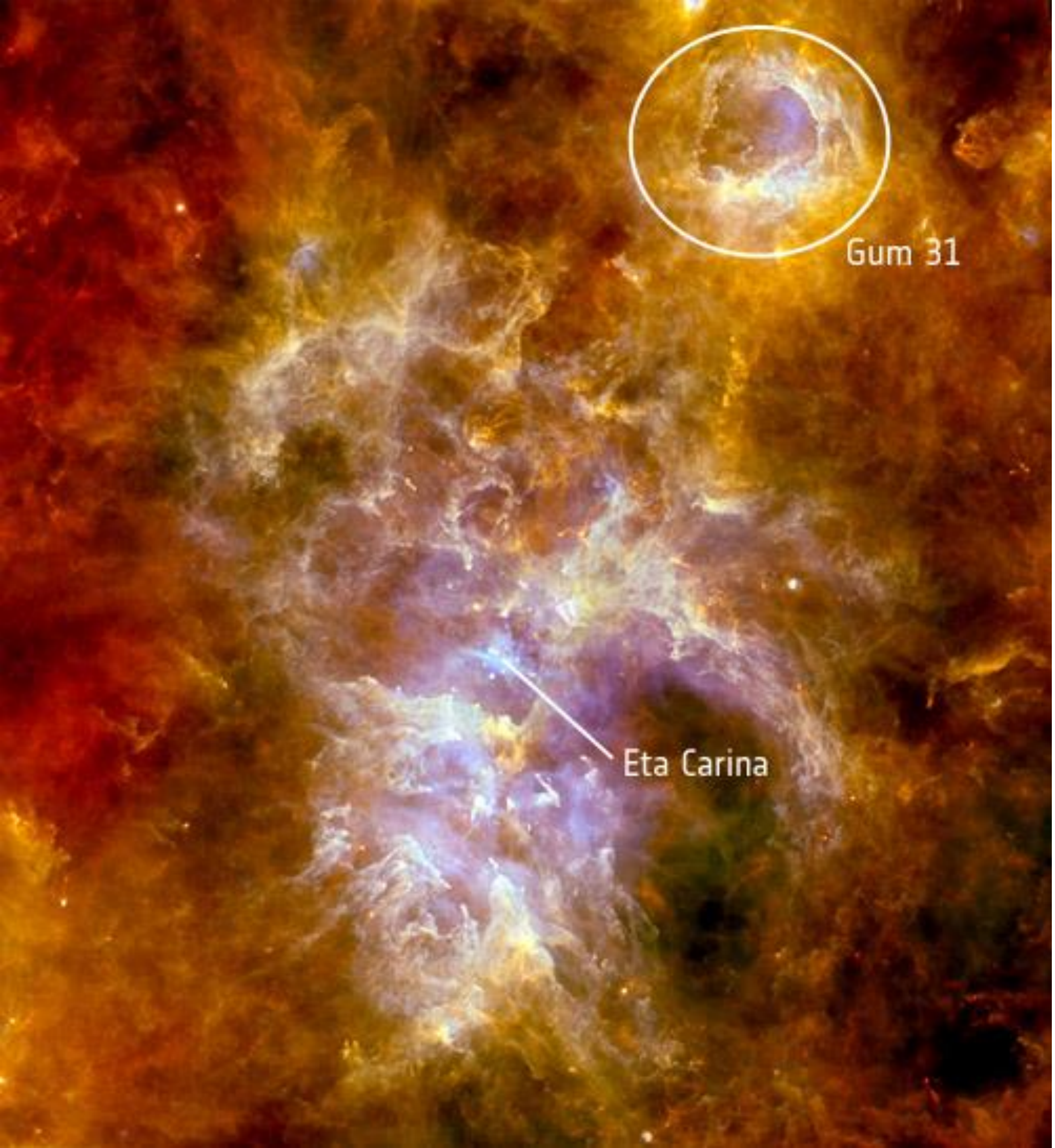
150 solar mass star: 10 million times more luminous than the Sun

2300 pc distant
=7500 light-years

Homunculus nebula: major axis ~ 20 arcseconds

Giant outburst of 1848 was studied by Sir John Herschel.

10 solar masses of material were ejected during the 19^{th}C.
The ejected nebula has 0.4 solar masses of 80 K (-190 C) dust

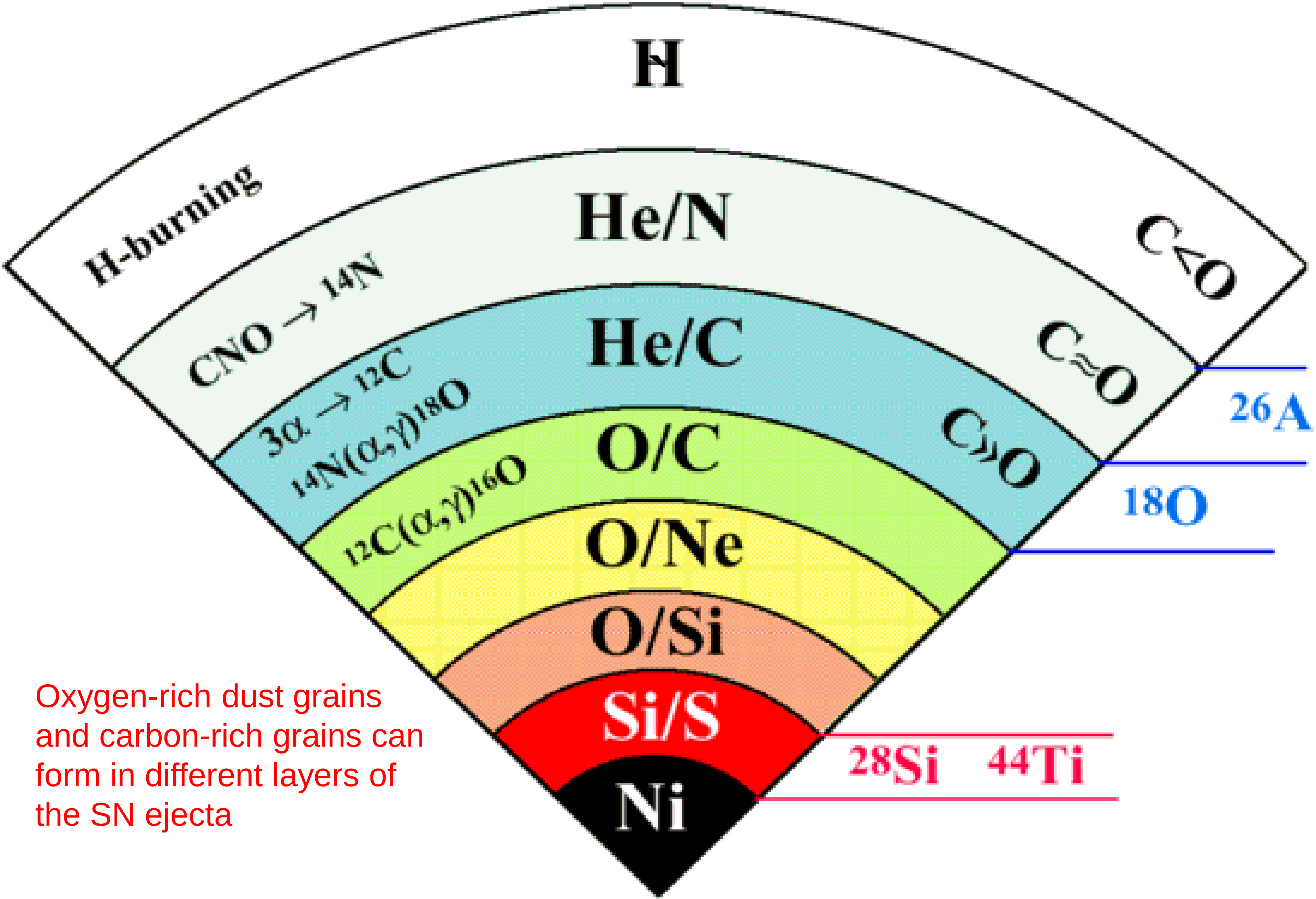


Eta Carinae: a supermassive star and future supernova in the Great Carina Nebula

Herschel 70/160/250um

2.3 degrees across

Onion-skin structure of a pre-supernova massive star

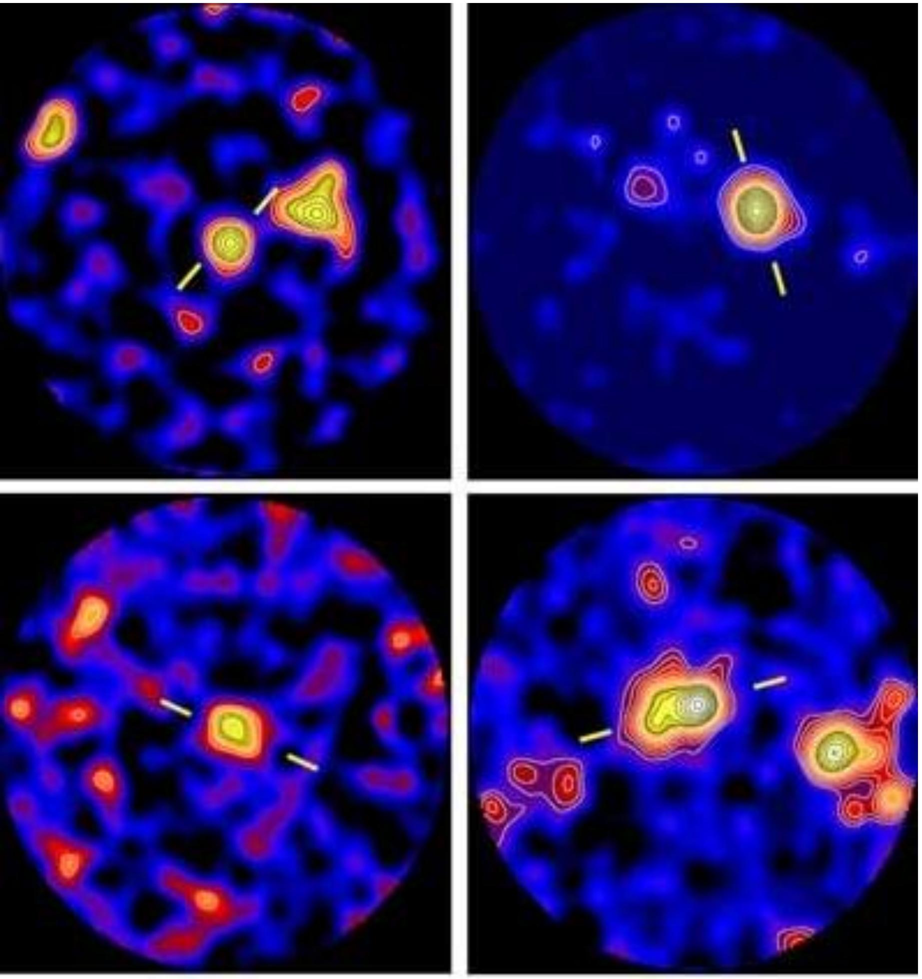


Oxygen-rich dust grains and carbon-rich grains can form in different layers of the SN ejecta

Surveys of dust-making stars in nearby galaxies indicate that in total they may not be making enough dust to explain the quantities of interstellar dust seen in these galaxies today.

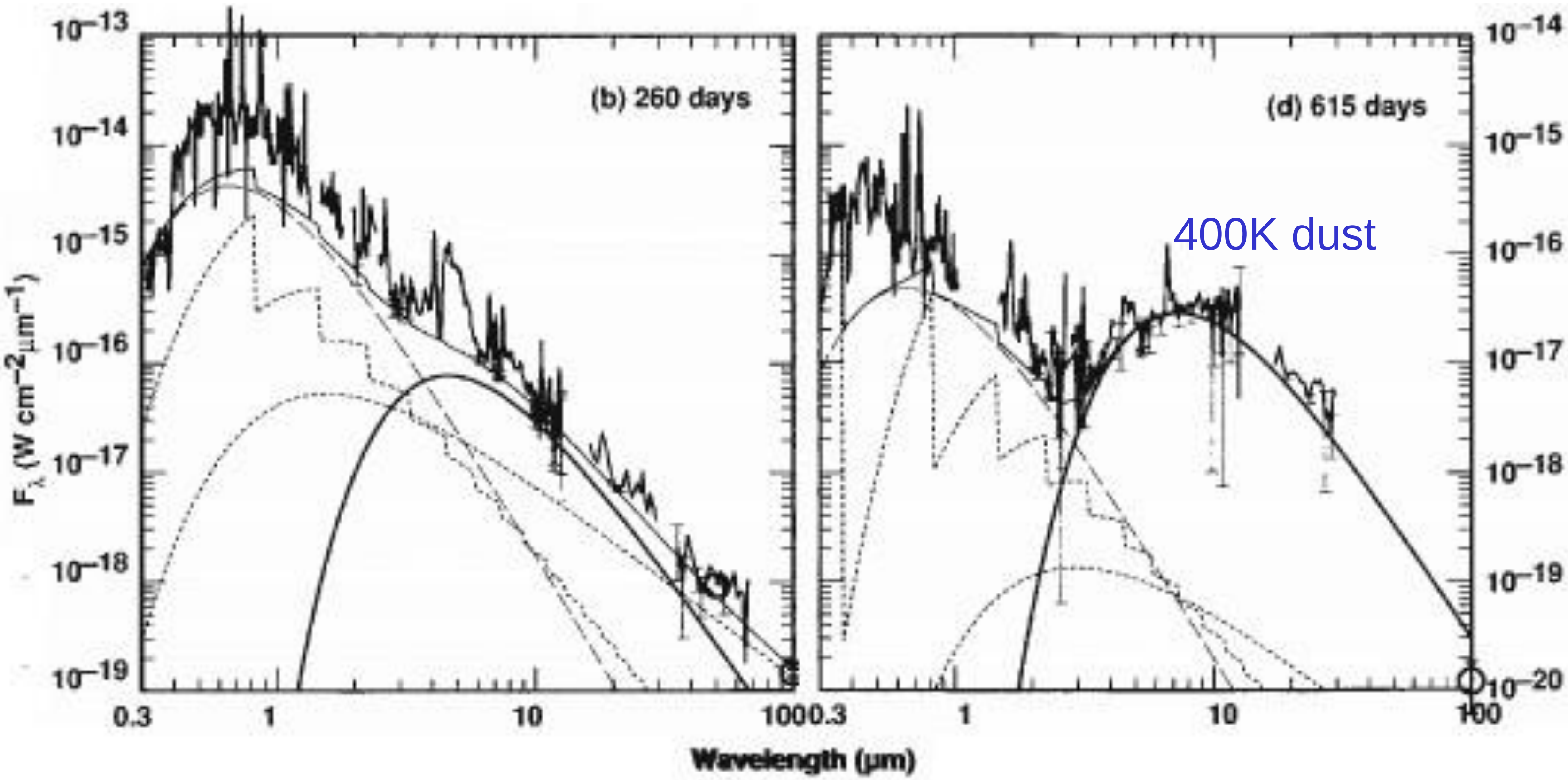
In addition, dust-emitting massive star-forming galaxies have been discovered at submillimetre wavelengths (e.g. by SCUBA). Several with redshifts z>6, emitting less than a billion years after the Big Bang, have been found to harbour more than 100 million solar masses of dust. Only high mass stars could make this dust quickly enough, via their supernova explosions.

But 0.1 – 1.0 solar masses of new dust would be needed from each supernova!



SCUBA submm images of IR-emitting high redshift galaxies

Dust formation in Supernovae



Airborne observations of Supernova 1987A, in the Large Magellanic Cloud galaxy, revealed the onset of dust emission during the 2nd year after outburst. However, the mass of warm dust was found to be less than 0.001 solar masses, much less than needed from massive star supernovae to account for the dust seen in high-z galaxies.

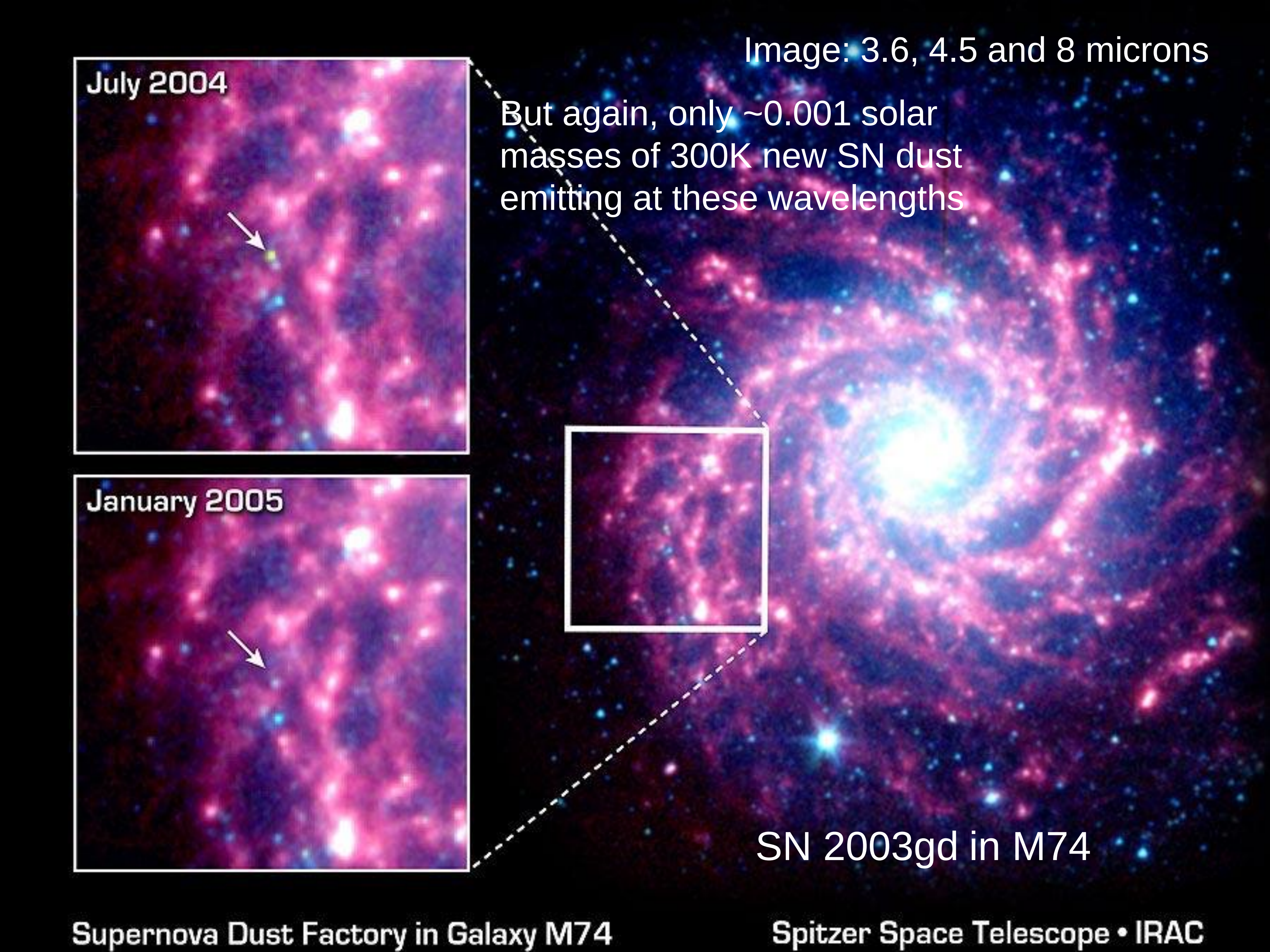


Image: 3.6, 4.5 and 8 microns
But again, only ~0.001 solar masses of 300K new SN dust emitting at these wavelengths
July 2004
January 2005
SN 2003gd in M74
Supernova Dust Factory in Galaxy M74
Spitzer Space Telescope • IRAC

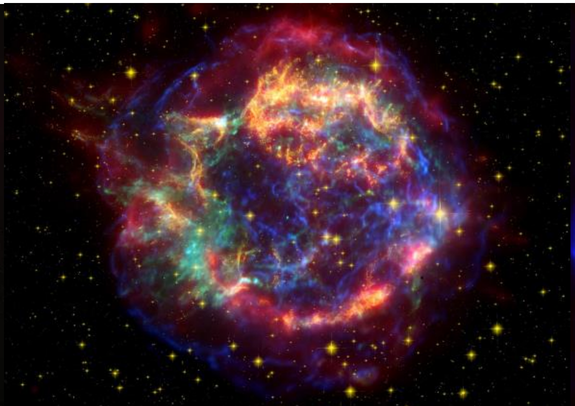
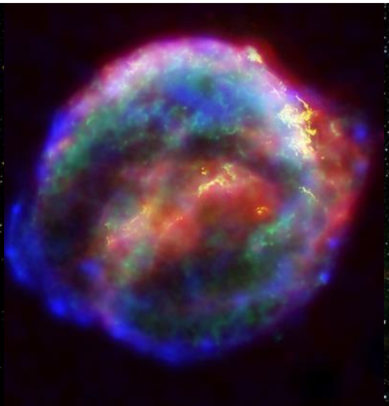
Can there be colder SN dust emitting at far-infrared wavelengths?

The Herschel Supernova Programme

Targets: 4 historical supernova remnants in the Milky Way

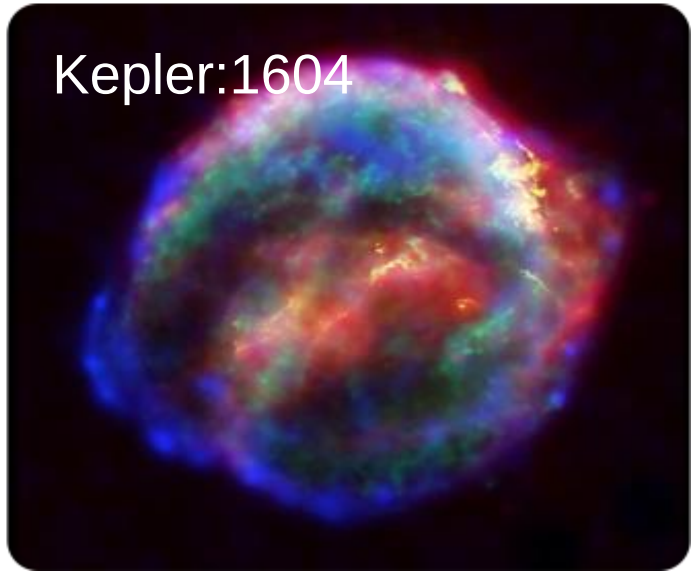
1680	IIb	Cas A
1604	Ia	Kepler
1572	Ia	Tycho
1054	II (pulsar)	Crab

All young: so swept-up interstellar gas mass is low

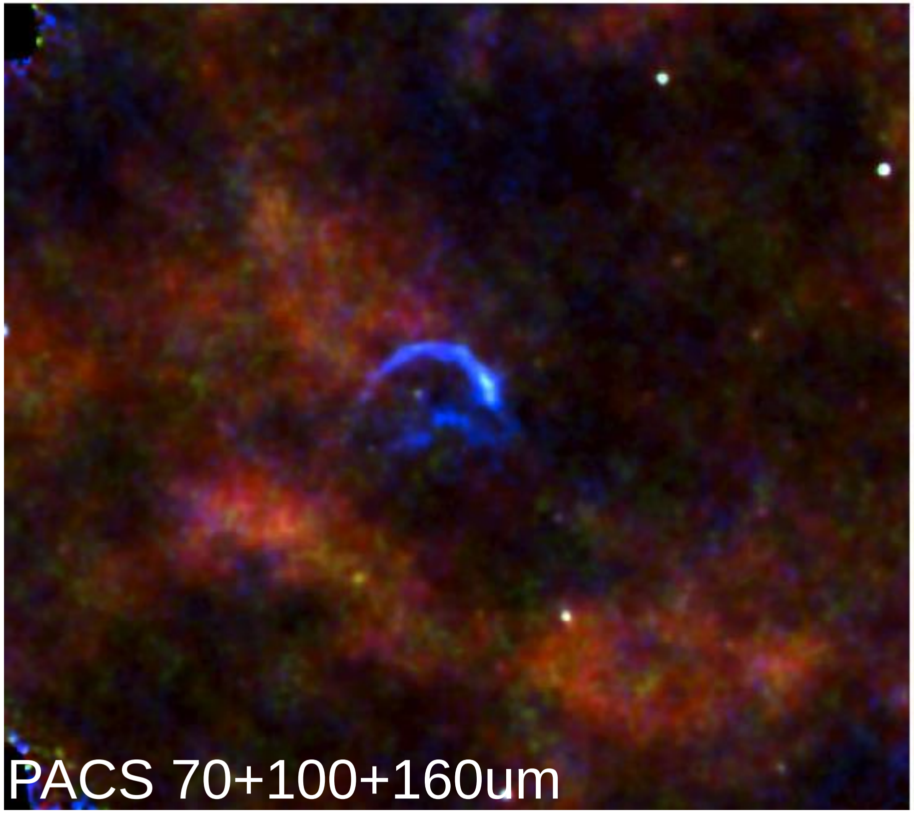

Type Ia (`standard candle') supernova remnants: produced by *low-mass* binary star systems

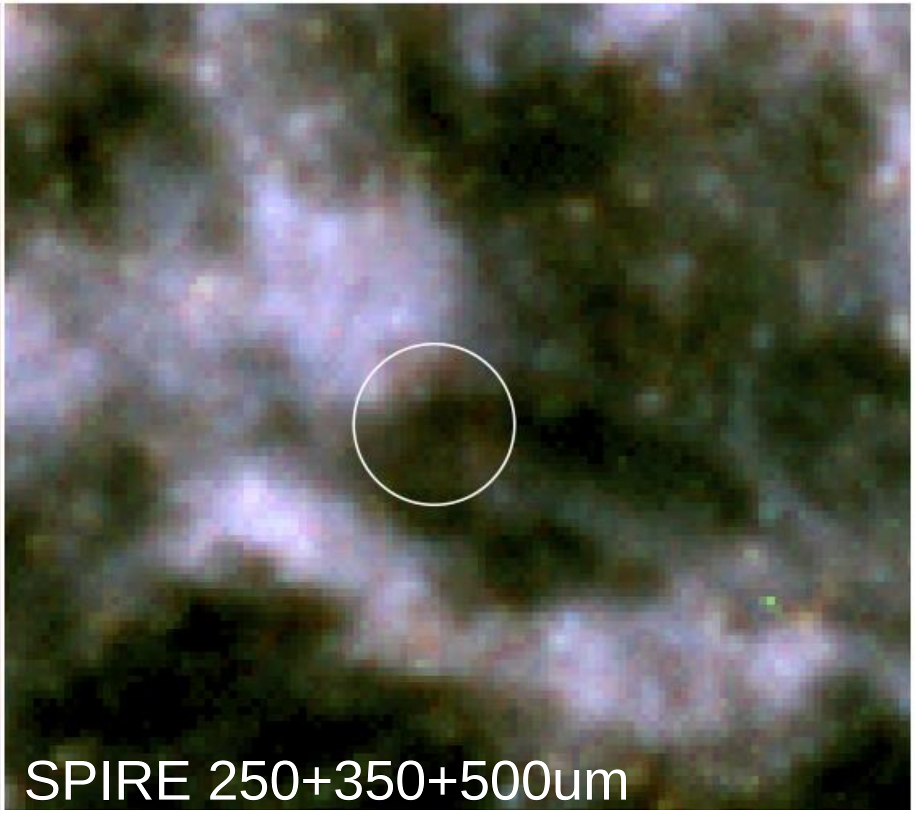
Type Ia supernovae are produced by the destruction of 1.4 solar mass white dwarf stars, and are believed to provide most of the iron atoms found in galaxies such as the Milky Way; ~0.6 solar masses of iron per Type Ia supernova.



X-ray(Chandra): blue
Visible (Hubble): yellow
Infrared (Spitzer): red

Kepler’s supernova remnant



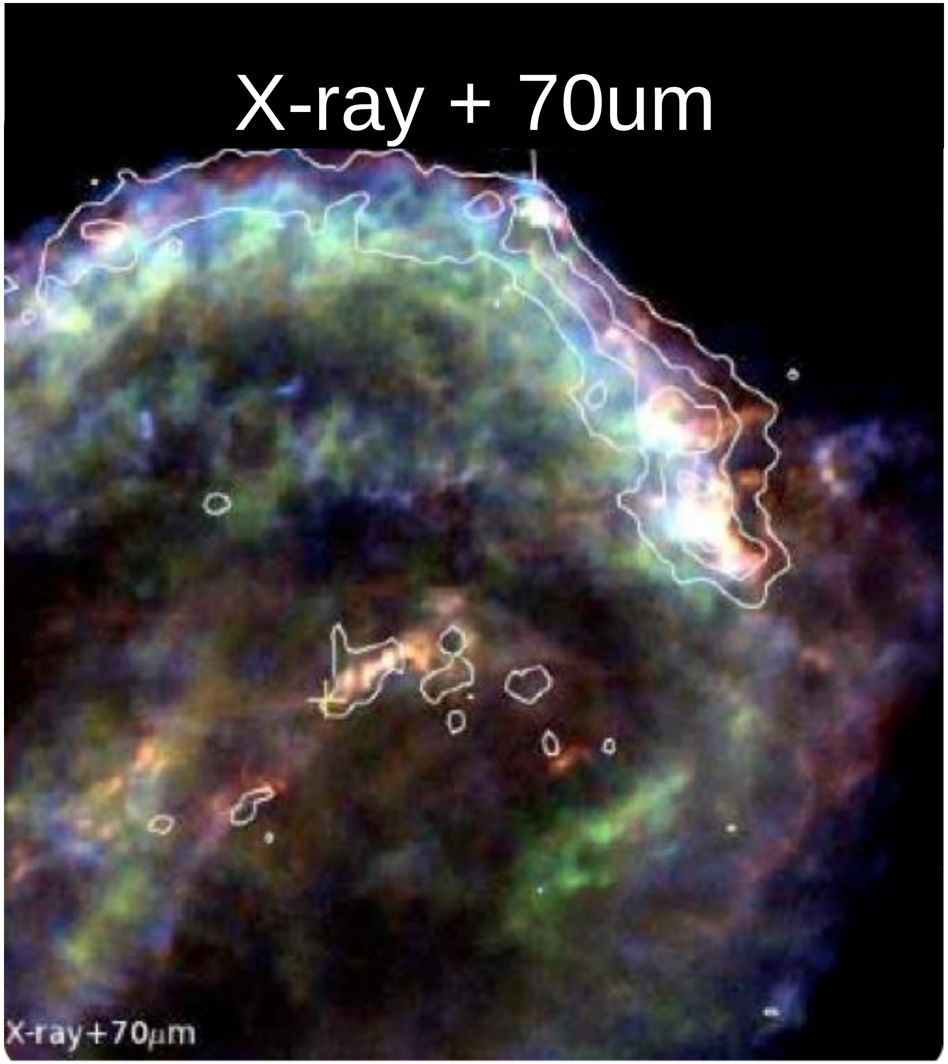


T=82+-5 K
M(dust) ~ 3×10^{-3} solar masses

Only foreground interstellar dust emission seen at these wavelengths

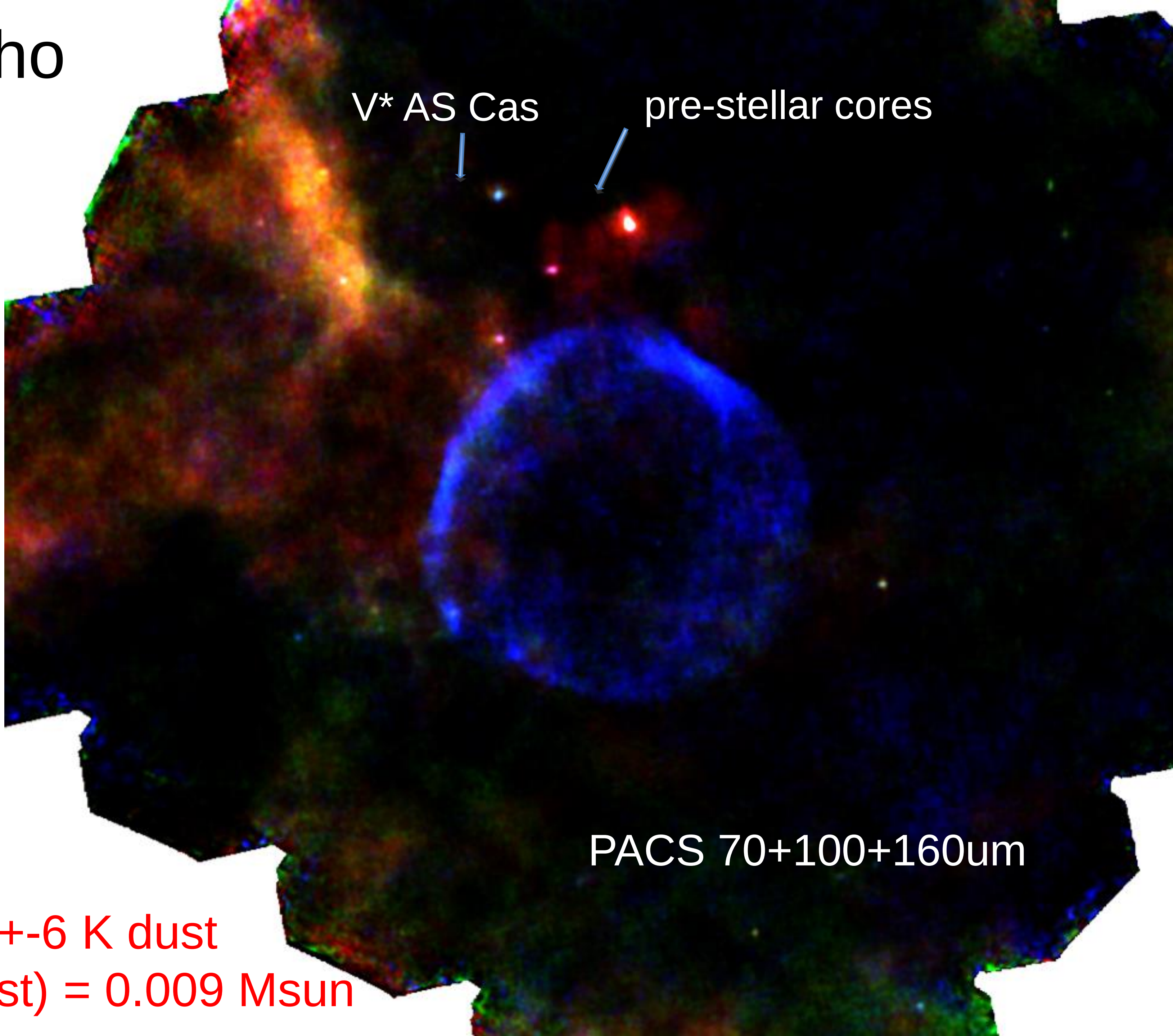
No cold (< 40K) dust inside the remnant

80K dust emission at the edge is spatially coincident with soft X-ray emission from swept-up, previously ejected, circimstellar material.



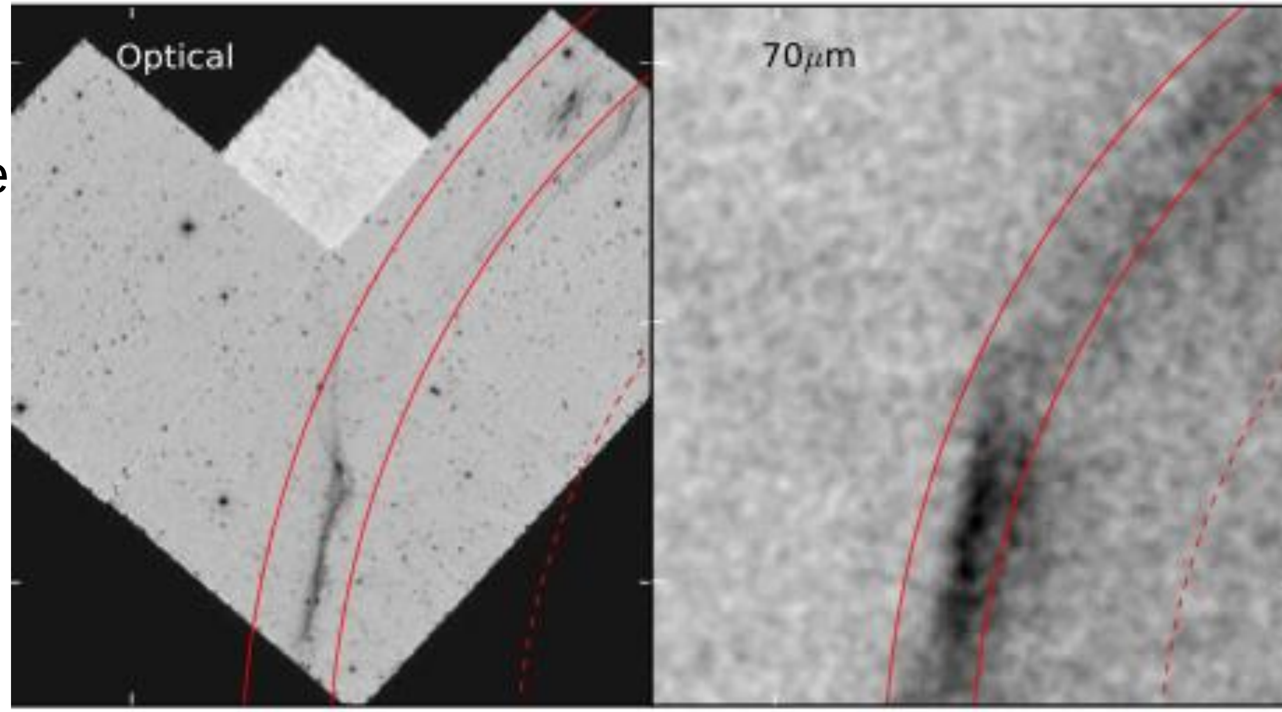
Kepler’s remnant

Tycho



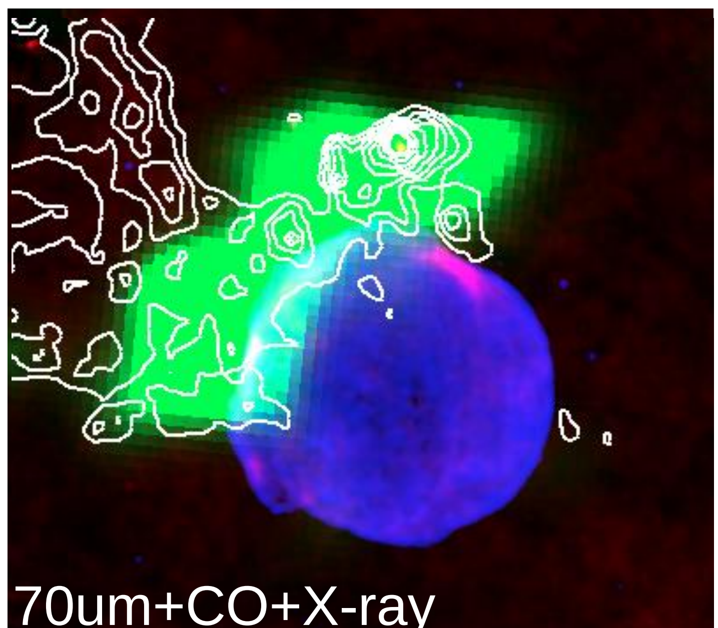
T=90+-6 K dust
M(dust) = 0.009 Msun

We see warm dust where the shock front meets surrounding gas

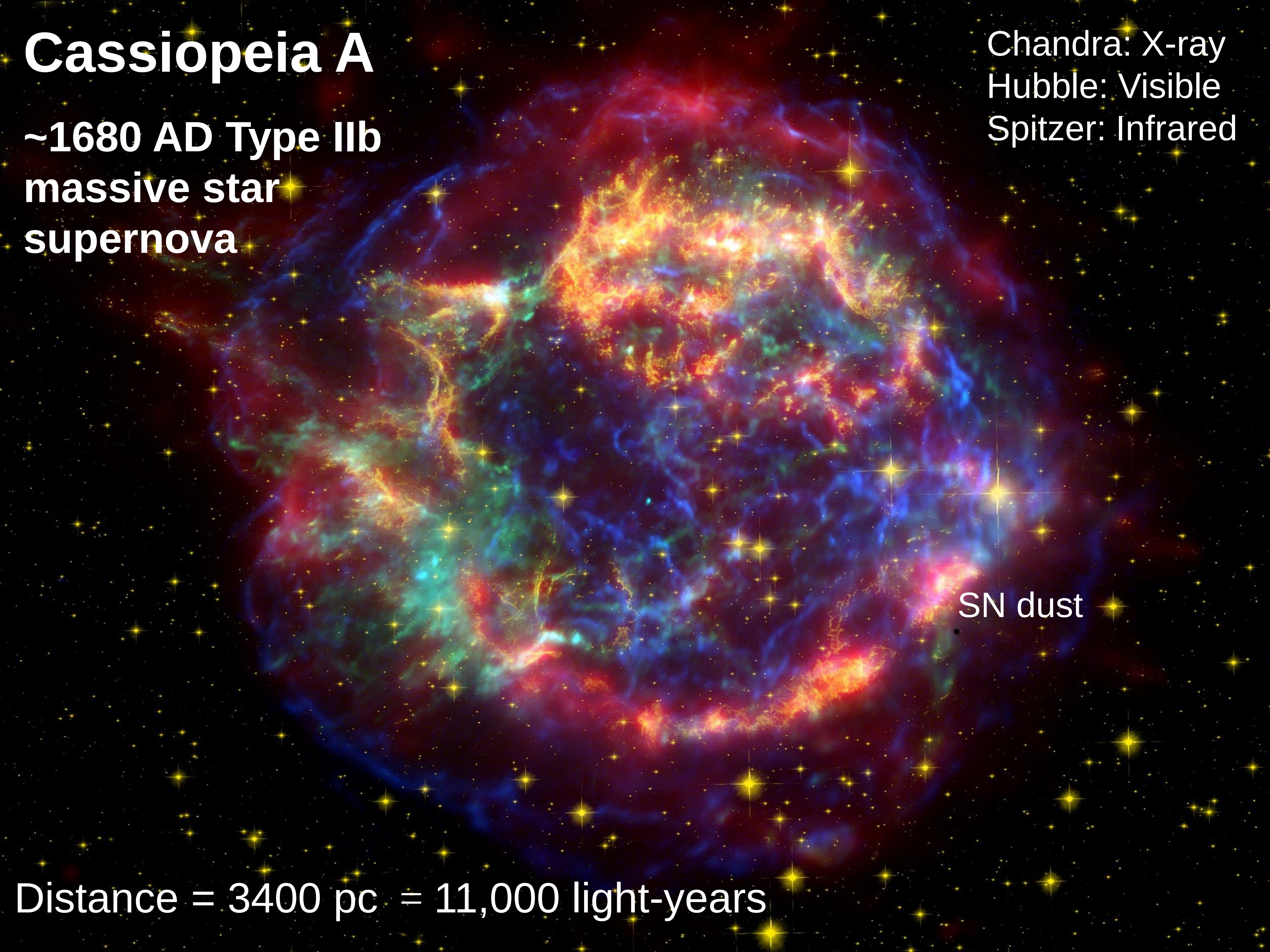


Tycho's remnant

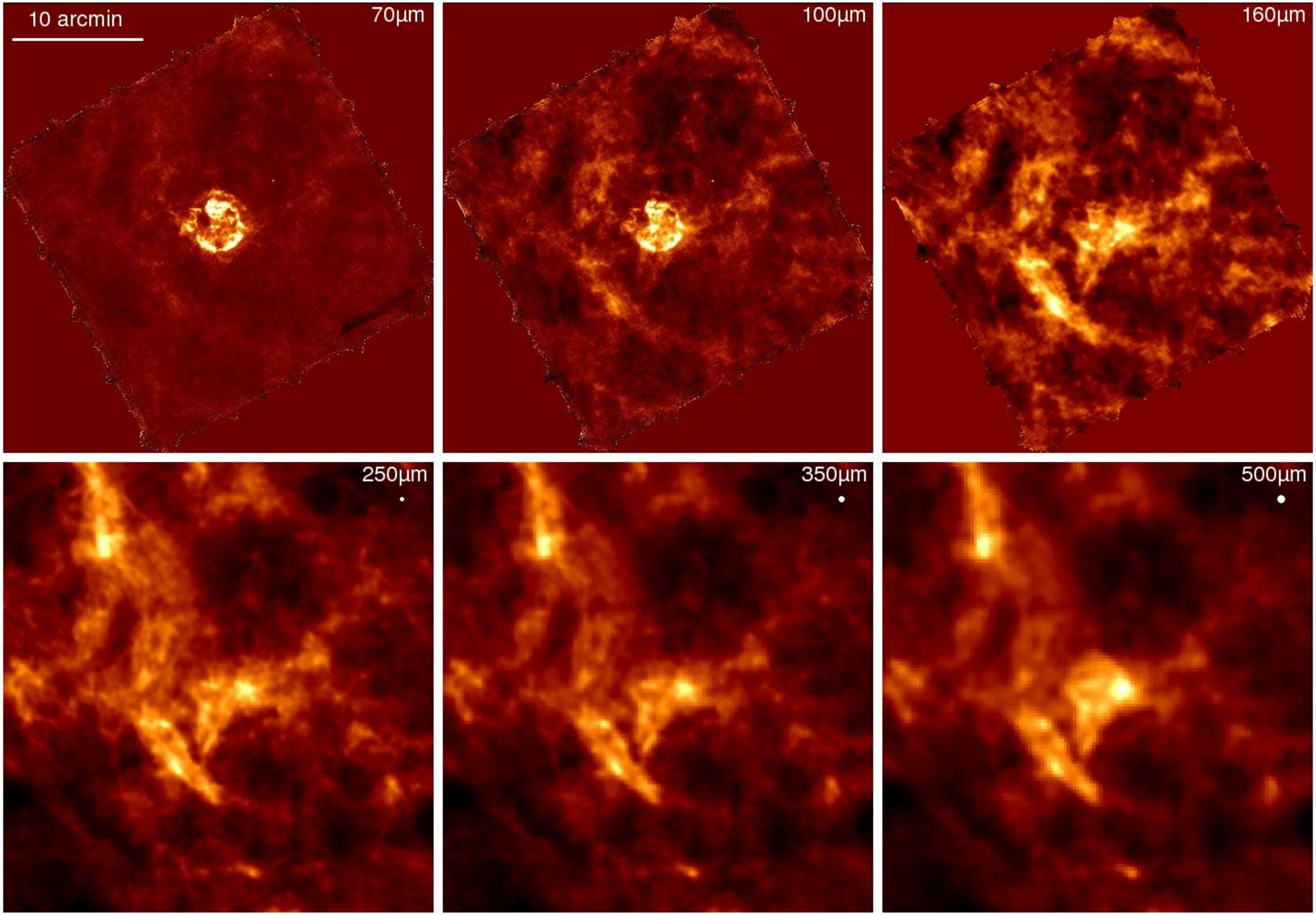
No cold dust inside the remnant – the warm dust at the edge is consistent with swept-up interstellar dust.

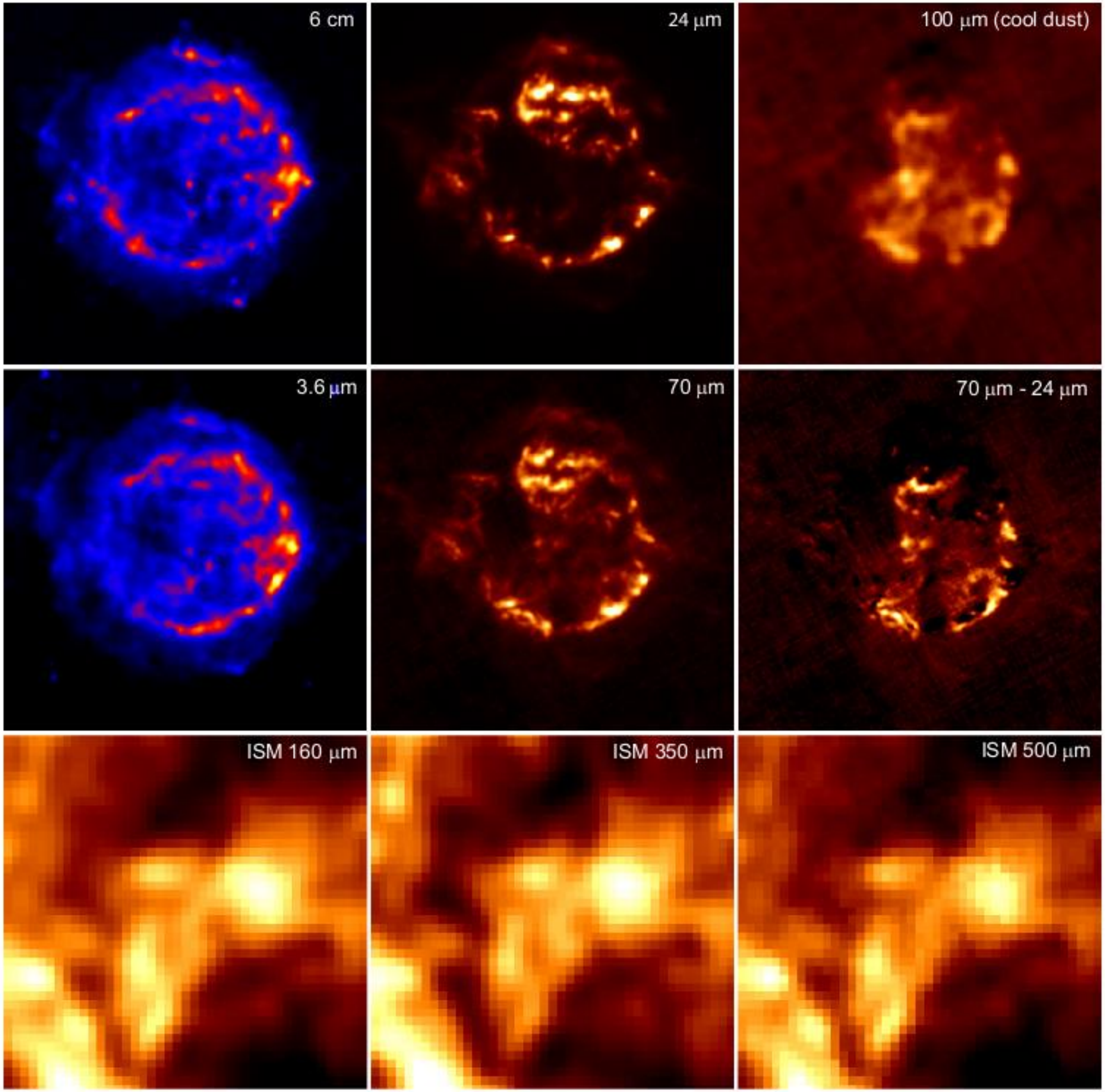


The absence of dust particles inside the Tycho and Kepler remnants implies that their iron atoms have failed to condense into particles.


Cassiopeia A
~1680 AD Type IIb
massive star
supernova
Chandra: X-ray
Hubble: Visible
Spitzer: Infrared
SN dust
Distance = 3400 pc = 11,000 light-years

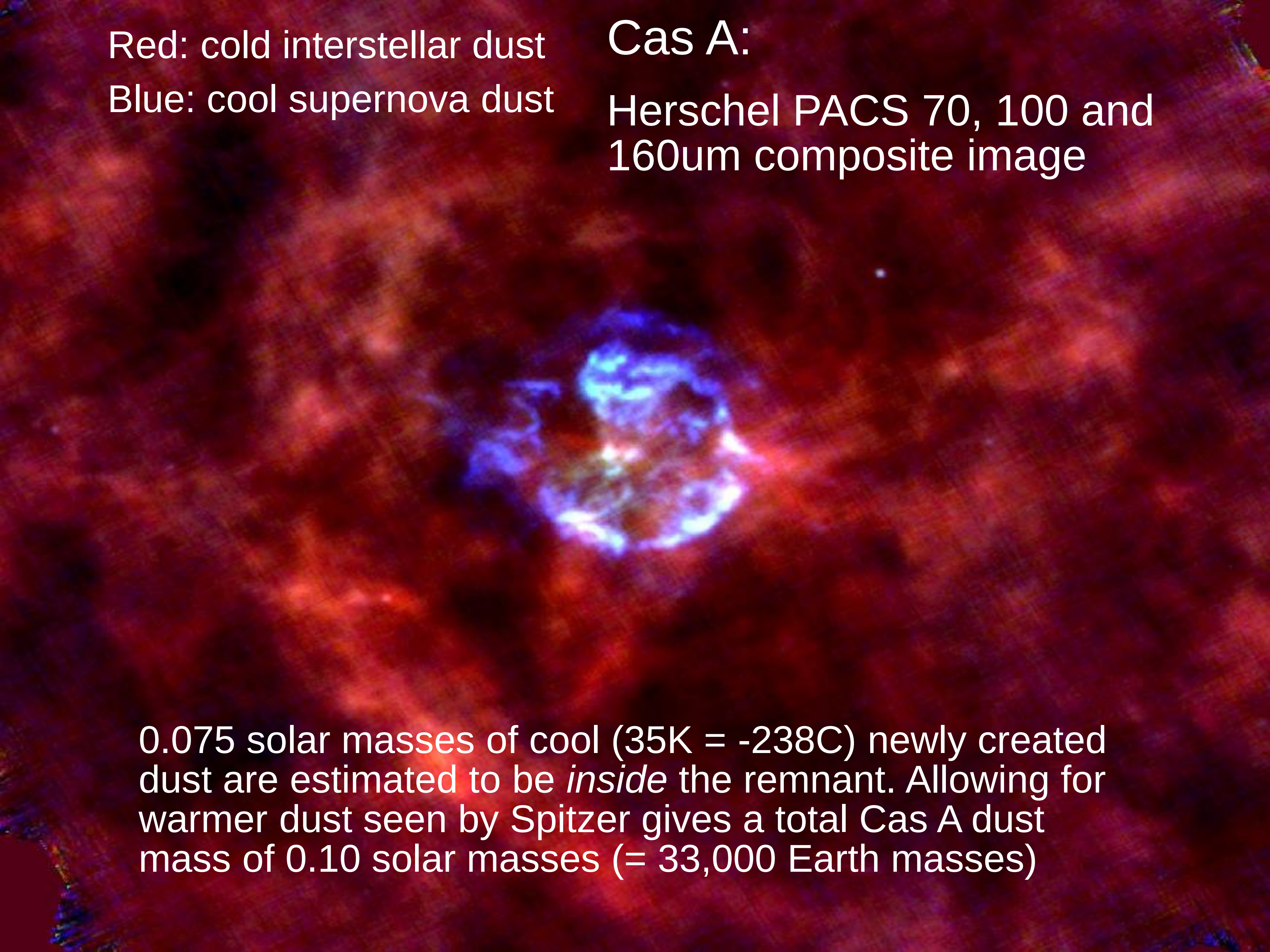
Cas A: wavelengths of 70-500 microns with Herschel

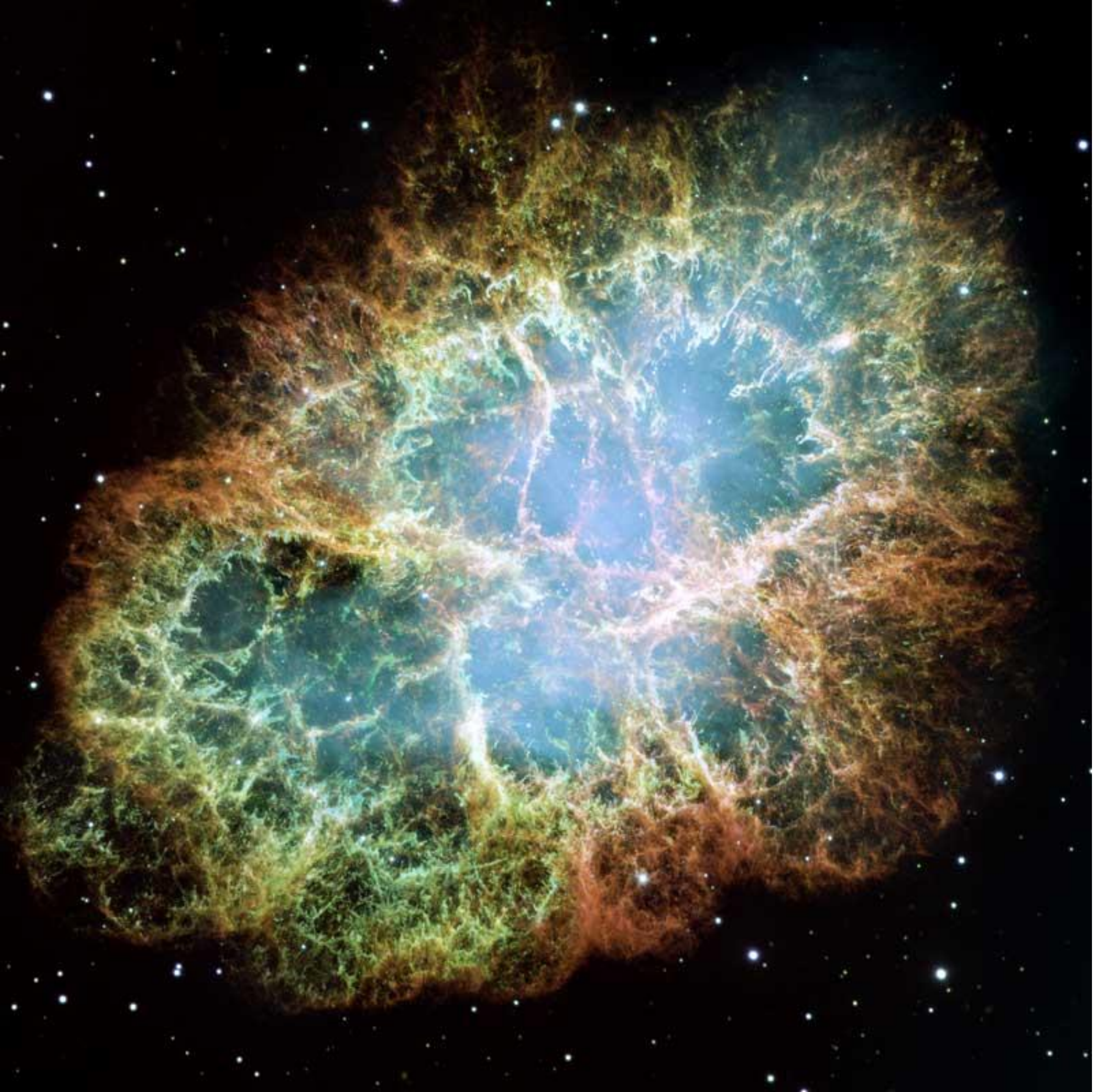




Cas A

near-IR, far-IR and radio images


Red: cold interstellar dust
Blue: cool supernova dust
Cas A:
Herschel PACS 70, 100 and 160um composite image
0.075 solar masses of cool (35K = -238C) newly created dust are estimated to be *inside* the remnant. Allowing for warmer dust seen by Spitzer gives a total Cas A dust mass of 0.10 solar masses (= 33,000 Earth masses)

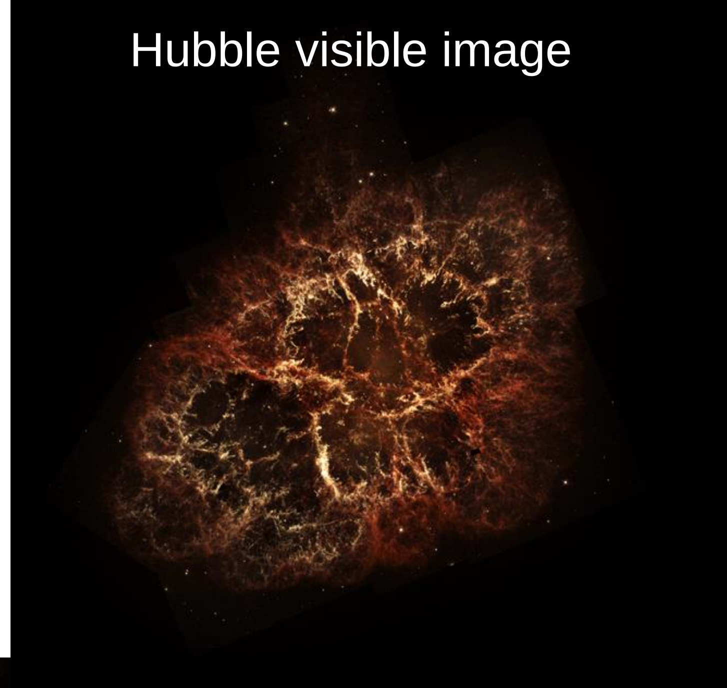


The Crab Nebula in Taurus: the remnant of a supernova explosion by a massive star, seen in 1054 AD.

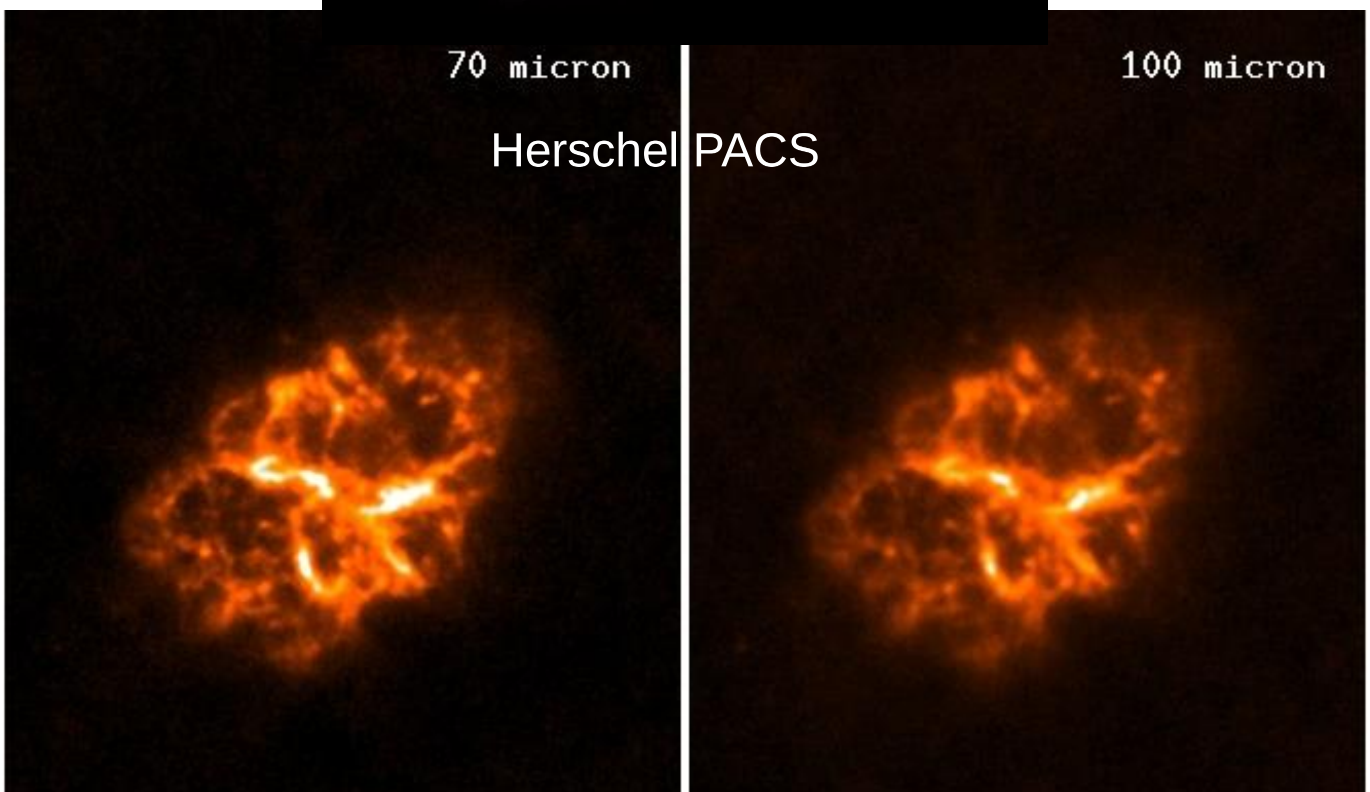
Distance = 2000pc = 6500 light-yrs

The Crab Nebula

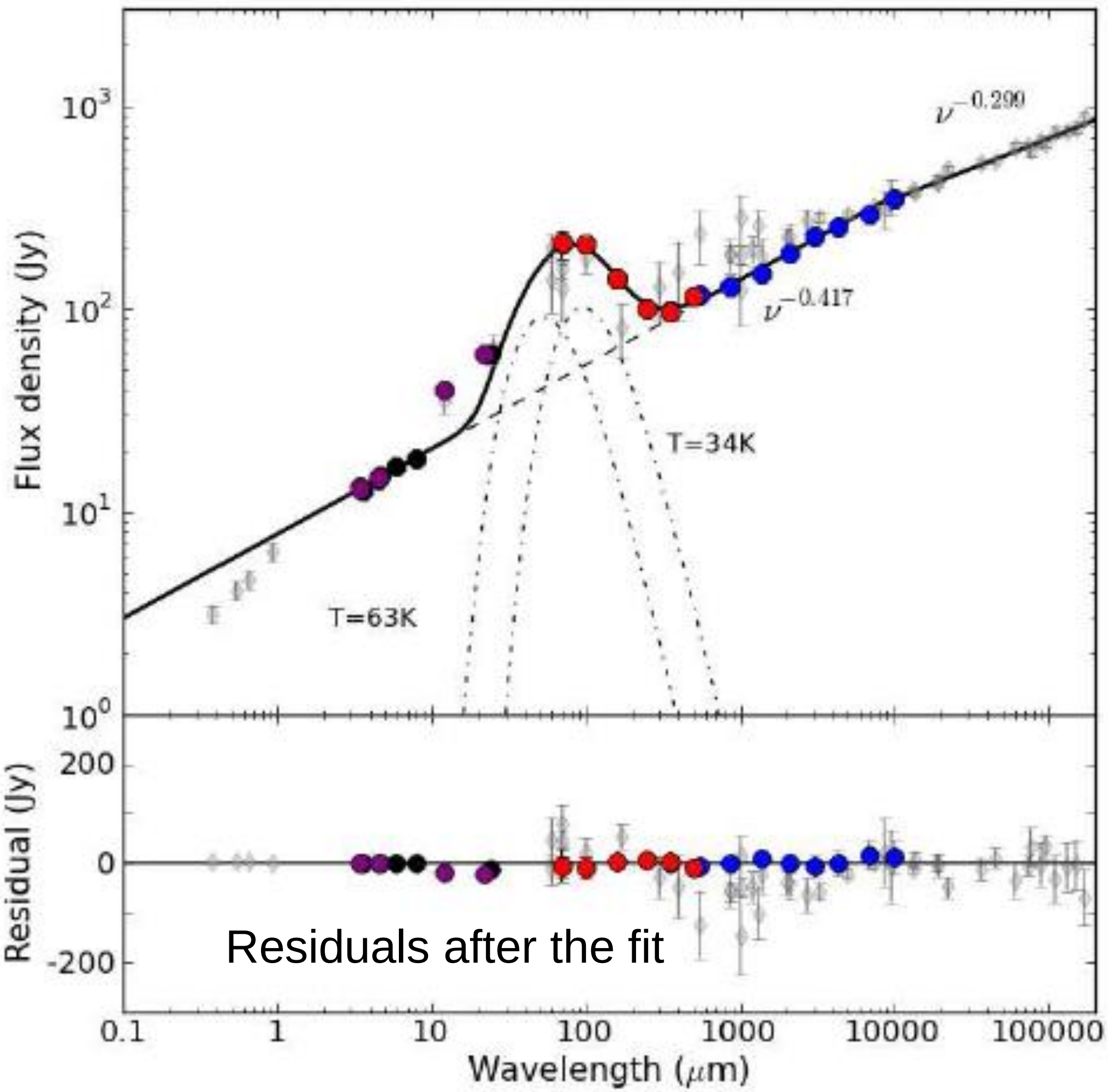
Hubble and Herschel images



Located in the outer regions of our Galaxy, where interstellar dust emission is weak.



The Crab Nebula's infrared spectrum



Residuals after the fit

Nonthermal synchrotron emission by high-energy electrons dominates in the near-IR and at mm-wave and radio wavelengths.

Interpolation and subtraction from the 70-250um Herschel fluxes (in red) allows the emission from `warm' dust (~63 K) and `cool' dust (~34 K) to be isolated and fitted.

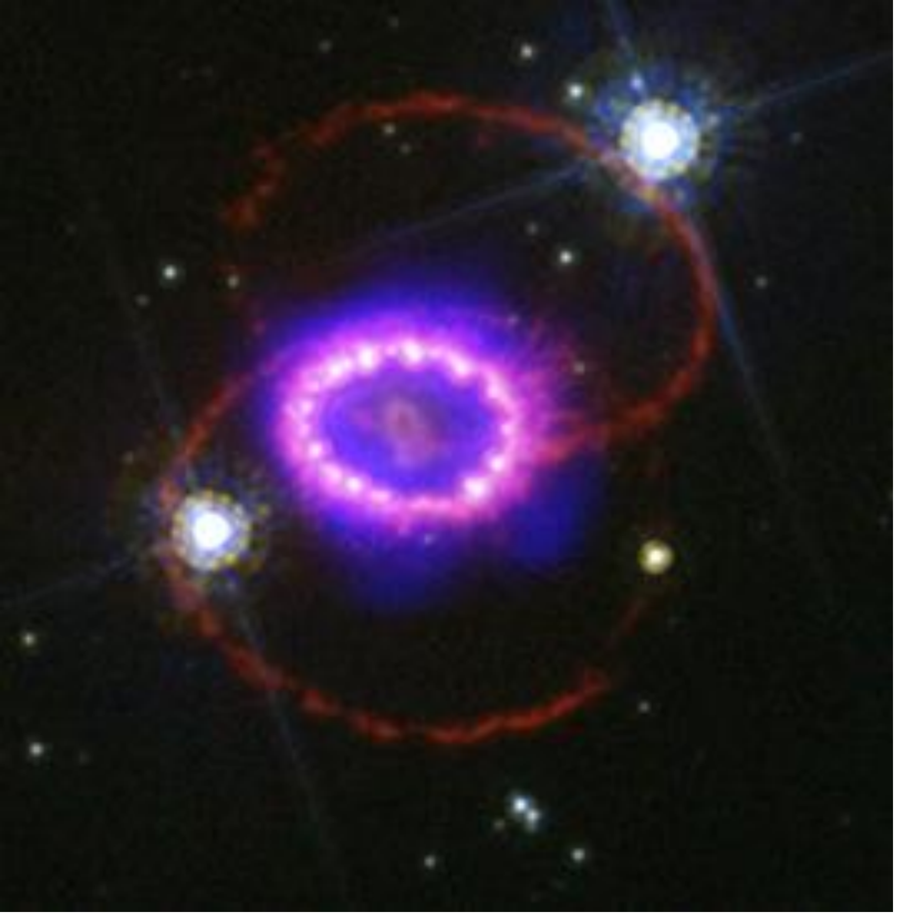
The total mass of new dust inside the Crab = 0.11 - 0.24 solar masses (= 37,000 – 80,000 Earth masses).

The Large Magellanic Cloud, a satellite galaxy of the Milky Way.

Supernova 1987A was originally discovered on February 23rd 1987

Distance = 50,000 pc = 160,000 light-yrs

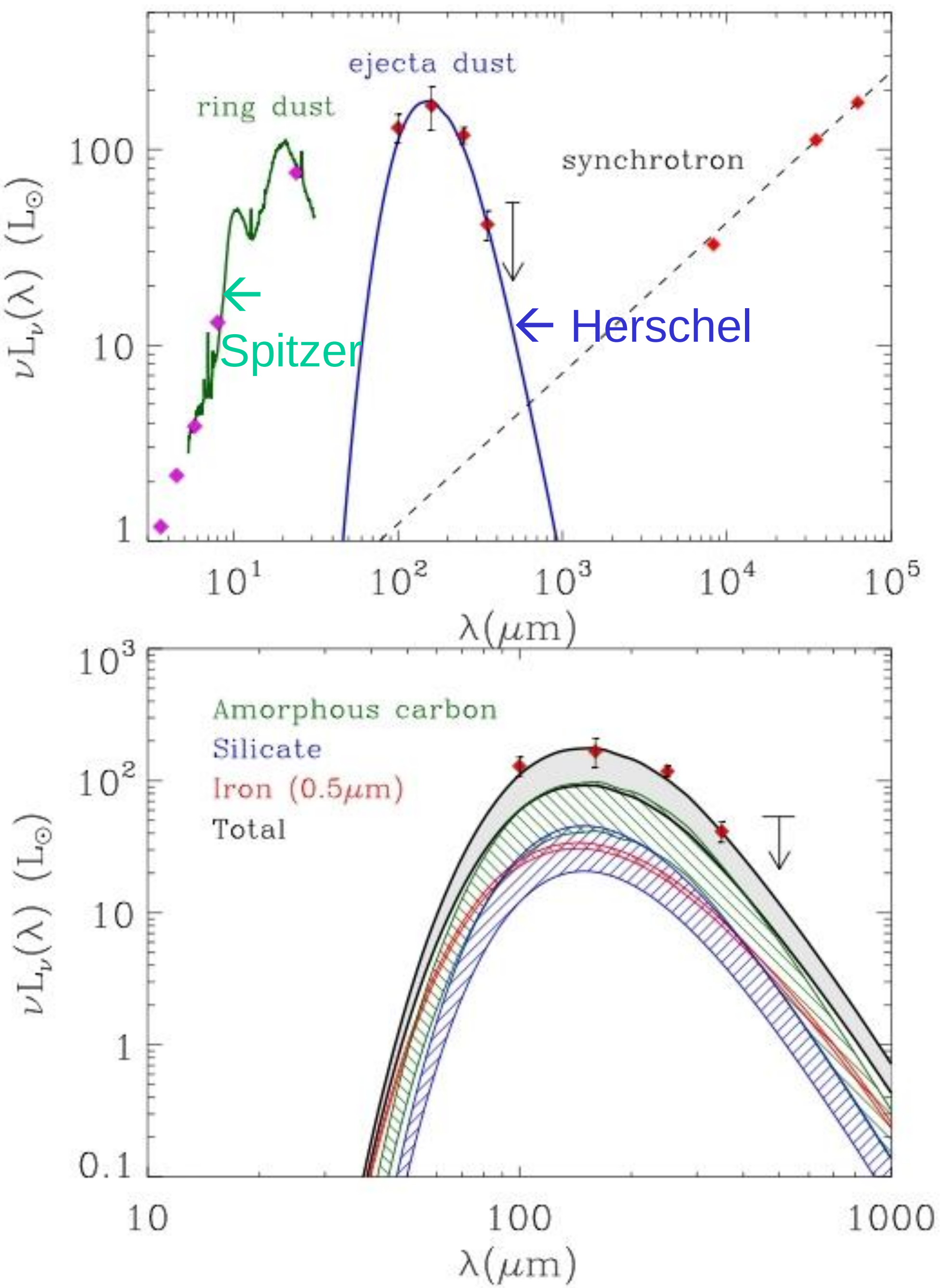
A recent Herschel/Spitzer image of Supernova 1987A, near the Tarantula Nebula

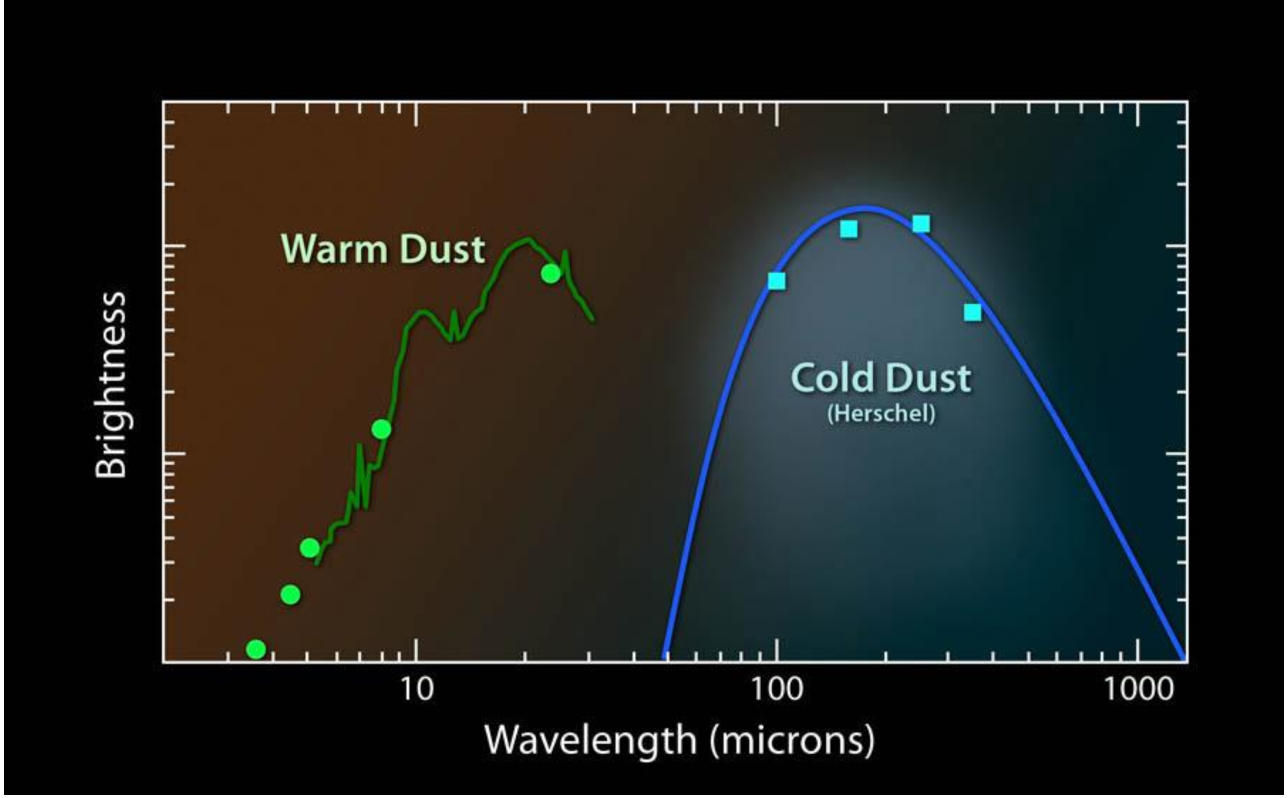


Supernova 1987A in 2005:

Hubble image showing the faint inner ejecta and the brightening ring of material that was ejected before the supernova event.

2010 Herschel spectrum of SN 1987A





The dust that was discovered by Herschel in SN 1987A's ejecta is so cold (~22 K) that a very large dust mass is needed to fit the observed emission.

No single dust species (e.g. silicates, iron, graphite) fits the observed emission without requiring more heavy element atoms than could be made in the explosion. However, a ***combination*** of all three dust species ***can*** fit the observed far-IR emission ***and*** satisfy the heavy element abundance constraints.

The mass of dust made by the supernova is estimated to 0.7 solar masses (=230,000 Earth masses)

Summary:

Herschel has uncovered more than 0.1 solar masses of cool dust in each of the three young massive star supernova remnants that it has so far observed.

So massive core-collapse supernovae may be able to account for the huge masses of dust found in very young luminous high redshift galaxies.